# U. S. ARMY

Technical Memorandum 12-72

# MILITARY REQUIREMENTS FOR RESEARCH ON CONTINUOUS OPERATIONS

Proceedings of a Conference
Held At
Texas Tech University
Lubbock, Texas
28-29 September 1971

David C. Hodge



April 1972
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## HUMAN ENGINEERING LABORATORY

## ABERDEEN RESEARCH & DEVELOPMENT CENTER

## ABERDEEN PROVING GROUND, MARYLAND





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13. ABSTRACT

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The Army is presently considering the feasibility of sustained and continuous operations. Recent technological innovations have rendered this continuous operations notion feasible from a technical standpoint; the question remains open as to whether man is equal to the task.

This conference brought together representatives of the Defense community and contractors presently performing research related to continuous operations, for the purpose of discussing the concept and attempting to formulate goals and/or gaps in our knowledge of long-term performance and recovery. This report contains the formal presentations to the conference, as well as the edited transcript of discussions following each presentation.

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Aberdeen Proving Ground, Maryland

## ABSTRACT

The Center of Biotechnology and Human Performance at Texas Tech University is conducting a research program titled "Performance, Recovery and Man-Machine Effectiveness" with Project THEMIS funding. This program's goal include investigation of task, environmental and nutritional variables affecting man's ability to perform for long periods of time, as well as factors influencing recovery from the effects of long-term performance.

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## PREFACE

How long can soldiers perform effectively under the stresses imposed by combat? Having performed, how long does recovery take? How may the onset of fatigue be retarded, or the process of recovery speeded? The Army needs the answers to these questions, and host of others to establish the feasibility of continuous and sustained operations which are being considered for future doctrinal implementation. Discussion of these questions formed the basis for this conference.

It is appropriate that this conference on "Military Requirements for Research on Continuous Operations" was held at Texas Tech University. The University's Center of Biotechnology and Human Performance is conducting a THEMIS-funded research program titled "Performance, Recovery and Man-Machine Effectiveness," the major portion of which is addressed directly to questions related to soldiers' performance and recovery in a continuous operations context.

Acknowledgement is due to those who helped make the conference a reality and success. Dr. Clay E. George chaired the Texas Tech University committee which arranged the meeting, and Dr. Richard A. Dudek and his staff transcribed the discussions and assembled the Proceedings package. Thanks are also due to Dr. Grover E. Murray, President of Texas Tech University, for providing facilities and support.

As we began to define the purpose and scope of this, the second human factors conference at Texas Tech University, it seemed to me that the topic of continuous operations is somewhat akin to the weather: everybody talks about it, but nobody seems to know what it means. There are several Army contract and in-house programs which are attacking various questions that are relatable to the feasibility of continuous operations, and both the Air Force and Navy are interested in the long-term performance problem area as well. Yet, nowhere can one find a compendium of gaps in our knowledge about long-term performance and recovery which could serve as a guide for increasing the cohesiveness of these projects. Furthermore, there does not appear to be any single, unclassified document which describes the present military thinking about this continuous operations doctrine.

The human factors research community, as a whole, needs concrete guidance as to what problems should be attacked first, as well as some statements about the relative efficacy of laboratory and field experimentation. This conference was held primarily for the purpose of providing some of this needed guidance.

In setting up this conference we wanted to obtain representation from three types of organizations: (1) those involved in the establishment of the continuous operations doctrine; (2) those responsible for establishing research priorities, or presently involved in funding and monitoring research related to continuous operations; and (3) laboratories which are presently conducting research programs which they (or we) think are relevant to the general problem area. To that extent, at least, the conference was a success. Mr. Jacob Barber, representing the Office of the Chief of Research and Development, set the stage for subsequent discussions by outlining the various types of military operations. He argued for placing primary emphasis on the most difficult problems first, notably the problem of long-term performance in combat operations. We are on the threshold of significant solutions to the night vision problem. As this last technical barrier to around-the-clock military operations is surmounted the question arises regarding man's equality to the task of performing around the clock. Mr. Barber emphasized his belief that the research community itself must participate in the establishment of research priorities and determination of the feasibility of continuous operations.



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Dr. Louise Speck addressed questions of interest to the U. S. Army Combat Development Command. In particular, she discussed the potential impact, on future Army operations, of personnel having various types of chronic or acute physiological deficiencies.

Other presentations from Army organizations included the Human Engineering Laboratory, and the U. S. Army Behavior and Systems Research Laboratory. Dr. James O'Hanlon of Human Factors Research, Inc., presented a digest of problems encountered in a survey of the biological literature performed under contract to the Human Engineering Laboratory.

Three papers were presented by members of the staff of the Center of Biotechnology and Human Performance, summarizing significant findings from their long-term performance and recovery investigations. There was also a presentation from the Human Performance Laboratory, University of Louisville, which has a THEMIS contract for research related to continuous and sustained operations.

A panel discussion by representatives of the Texas Tech University administration treated problems and advantages of inter-disciplinary research in academic settings.

The conference content was summarized by Dr. Carl J. Lange, of George Washington University.

Lively discussion followed each presentation. This discussion was tape-recorded and subsequently transcribed. The transcript was condensed to make it more readable, but every effort was made to preserve the content and issues raised. The undersigned assumes full responsibility for any errors introduced by the condensation process.

A question of continuing, urgent concern is the relation between laboratory and field experimentation. Decrements are easy to demonstrate in laboratory studies, but field trials typically have not shown large performance decrements. The relative lack of experimental control which seems to characterize most field studies does not appear to be a plausible explanation for all of this difference. Perhaps organizational or motivational factors are operating in the field which are difficult to recreate in the laboratory. In any event, this situation forces us to consider whether, or to what extent, laboratory data may be useful in predicting performance in the field. If laboratory experimentation related to continuous operations, as presently being pursued, does not produce data which is useful for predicting field performance then the laboratory studies must be revised to make them predictive.

This conference has essentially exhausted the likelihood that the problem can be resolved by discussion alone. An altogether different approach should be attempted. Through private talks at this conference, it was determined that the consensus of the various laboratories' representatives is that the following approach should be considered. The U. S. Army Combat Development Command should publish scenarios for combat operations of a sustained or continuous type. Existing data from the various "continuous operations" programs should be used to predict soldiers' performance in field studies conducted according to portions of the CDC-developed scenarios. If the prediction is successful, then we will know that the laboratory data is useful, and these data should be used to develop predictive models for future long-term combat operation. If the prediction is unsuccessful, then we should re-think our laboratory research programs and redirect them toward variables which will provide the needed prediction of real-world performance.

DAVID C. HODGE
Editor

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REMARKS ON RESEARCH REQUIREMENTS FOR CONTINUOUS OPERATIONS

Mr. J. L. Barber
Behavioral Sciences Division
Office, Chief of Research and Development
Department of the Army

Gentlemen:

I am delighted to be here with you at this conference to discuss research requirements for continuous operations. However, when we discuss this subject, I believe we are in a "chicken and egg" situation. If we knew the concept, the policy, the plans and constraints concerning continuous operations, we would be in a better position to define the information requirements and to project the kinds of research that would be useful. However, we do not enjoy that unambiguous situation. Instead, we as a research and development community are being asked to participate in describing what is possible, how it may be feasible, and what is likely to be required if continuous operations are to become practicable from the human point of view.

In an article of two years ago, Dr. Donald MacArthur, who was then in the Office of the Director of Defense Research and Engineering, put it this way: "...the single most important job of defense research and development is to think - and think hard - about the options and the capabilities which the President and the Secretary of Defense may need in the future. We try to do this. Usually when we finish, we have a long list of projects, designed to guard against a range of contingencies and to prepare for a range of sometimes relatively improbable needs. At this point, of course, the list is cut based upon the national priorities and the budgetary constraints. The crucial point, however, is that research and development is in the option-creating business, leading to ways of fulfilling national commitments with alternative methods, building new understanding of the interactions between policies, missions and technologies."(1) Dr. MacArthur was not speaking specifically about continuous operations but was addressing the general subject of forecasting future military missions and their technological demands. We in research and development are being asked to help determine, from the standpoint of man's capabilities, whether or not continuous operations are, or can become, a practicable alternative.

If we have not the benefit of a statement of policy, what do we have as a point of departure? In fact, there is much to guide our thinking about the research requirements for continuous operations. Although that guidance is not specific and detailed, I believe it is adequate to recommend some directions of effort as being more relevant than others.

At this point it is appropriate to delineate more carefully what is meant by continuous operations. Here we draw upon the groundwork of Colonel Joseph Marks, formerly with the US Army Combat Developments Command, Institute of Advanced Studies. Colonel Marks was among the first to attempt to delineate Human Factors Support Requirements for Continuous Operations in a paper under that title delivered at the Army Human Factors Research and Development Conference in November 1969. As Colonel Marks put it, "The concept of continuous operations as now being developed does not envision a battlefield environment at which the same level of intensity will last indefinitely. Combat operations will still consist of movement to contact, periods of fighting, consolidation, regrouping, resupply, and continued fighting. Significantly, however, the varying operational cycles will be influenced by the unit's capability to fight effectively for longer periods of time and not by the fluctuating environmental conditions of night and day.

To place continuous operations in still better focus, the terms 'sustained operations' and 'continuous operations' as defined in the concept are separate types of operations. 'Sustained operations' are those smaller unit actions conducted by brigade, battalion, and company for a given number of days to achieve a limited objective. During hours of darkness, there occurs a definite slackening of intensity and applied combat power. In contrast, 'continuous operations' are planned and conducted by division or higher unit, and application of combat power will remain at about the same level of intensity and efficiency throughout the 24-hour period and for periods of fighting extending into weeks.

It immediately becomes clear that if we are to achieve a capability to operate continuously on the division or corps level, people will be required both night and day to carry out the functions of combat."(2)

These definitions of continuous and sustained operations are satisfactory for our purpose today. Perhaps they do not allow for one subject that is scientifically important. That is the subject of the influence on performance of the disruption of circadian rhythm resulting from long air flights. Admittedly, long air flights are not an essential part of continuous operations. Nevertheless, long flights could precede continuous operations, and in that event, the effects of circadian rhythm on performance do become relevant.

Without belaboring the obvious, let us note that there are two fundamental reasons for any mode of operation other than continuous operations. These reasons are: man's relatively ineffective vision at night and man's limited endurance. But for Army operations there is much more to the problem than these two fundamentals. Sailors solved the problem of continuous operations hundreds of years ago, and they solved it without the additions of large amounts of artificial light. In more recent times we find air operations feasible around the clock. These depend very heavily upon a sophisticated technology, as, of course, do modern maritime activities.

The point is that the nature of the activities or tasks to be conducted, and the environmental conditions in which they are conducted are crucial factors in determining the complexity and difficulty of the problems of operating at night. For the Army this includes an almost unlimited variety of individual tasks and a multiplicity of unit missions. These are conducted primarily, but not exclusively, on the ground and are conducted under a large range of environmental circumstances in terms of terrain, weather and climate.

If the problem is so tough, why then raise the issue of continuous operations for the Army? As Dr. MacArthur put it, "Too often there are unexpected problems, new solutions, unforeseen issues, unpredictable events. The Defense Department may be asked to carry out a mission on short notice which no one anticipated and this perhaps distinguishes defense research and development from the research and development supporting other national goals."(1) In short, we can't always predict what the enemy is going to do. What if he forces us into continuous operations? Although that is reason enough for interest in continuous operations, there is a more specific reason. Colonel Marks stated that reason quite succinctly: "Military concept studies in the long range timeframe indicate that technology will develop night vision equipment that will permit a capability for ground forces to operate with near daylight efficiency. Also, the forecast is that major combat vehicles and equipment will reach such improved states of ruggedness and operational effectiveness as to support continuous operational periods much beyond those now accepted or practiced."(2)

Therefore, if one postulates a solution to the problem of "seeing" at night in the sense of having the detailed information requisite to full military operations, then the difficulties are reduced to those that stem from the limitations on man's endurance, the nature of the activities, and the environment.

If we set aside environmental and climatic extremes in order to avoid being side-tracked into areas where environmental considerations become paramount, such as operations in extreme cold, then we arrive at the point where we can consider the question of man's endurance and the interactions with the nature of the activities in which he is engaged.

We postulated a solution to the problem of seeing at night. How realistic is such an assumption? "An area of development effort that ranks very high on the priority scale is STANO - an acronym for surveillance, target acquisition, and night observation. With the momentum generated by the post-war scientific and technological revolution, we have made remarkable progress in tactical mobility and in firepower. We have made progress, too, in ways of finding the enemy, but not at the rate where we can use the increased mobility and firepower to the best advantage.

Advances in technology using infrared, image intensification, photography, and many other techniques are providing the developmental base to bring surveillance and target acquisition - under all conditions of weather and visibility, abreast of mobility and firepower. However, there is the danger that the proliferation of these devices can flood the combat units with so much data that timely proc.ssing in real-time becomes a problem and a key factor in their use. STANO is the program that will tie all of this together.

Night Vision devices are an important part of the STANO developments program. Individual and crew-served weapons sights that us passive image intensification devices that amplify starlight and m nlight many thousands of times have been adopted as standard items. . second generation of these devices are now under development to achieve better resolution and performance, as well as reducing cost and size.

Until these second generation devices become available we are continuing to find new and better ways to use devices that are within or pushing the current state-of-the-art. One such device is the Iroquois UH-1 Helicopter, modified to be used at night. This helicopter, called the INFANT, uses a direct view image intensifier and a low light level television to search for and engage the enemy. The on-board weapons are boresighted with the sensors and track in azimuth and evaluation. Several of these ships have been used in Vietnam with excellent results. During a month of operational testing in Vietnam the INFANT system attained an engagement rate of nearly 50 percent - or finding and engaging a target every other sortie. The targets knocked out included enemy personnel, sampans, and light weapons.

Another device that has shown great promise during its early testing is the Handheld Thermal Viewer. This device, unlike the image intensifiers, detects targets based on their natural emission of thermal energy; thus, the viewer is completely passive, is not dependent upon the presence of any starlight or moonlight and has a real all-weather capability."(3)

These are but a few examples from among the kinds of equipment existing or under development. While they do not completely establish the postulate of being able to see at night as a fact, at least they remove it from the realm of the unreasonable.

At this point, I want to further press upon you the argument that requirements for research related to continuous operations have their origins in and are guided by the activities to be performed. Each of us is challenged to devise research requirements from our understanding of missions and military activities that the Army must accomplish. We are also challenged to describe with the greatest possible specificity the applicable domain of any work undertaker

This meeting is not long enough to consider in detail all of the Army missions and military activities that would need to be examined in order to derive specific research requirements. However, we can examine the relative priority of interest among broad mission categories as an initial step in pointing toward the most useful topics for exploration.

Dropping back to basics, most of you know that the Army categorizes its field operations as combat, combat support, and combat service support. Included in combat service support are those functions of which logistical services, administrative services, equipment maintenance, and medical services are representative. These are primarily functions which can be and usually are organized and located to operate around the clock upon demand.

The combat support functions are those typified by military intelligence, signal, military police, and engineers. Here we encounter missions conducted under greater threat of enemy action, the use of light becomes increasingly hazardous and darkness a serious impediment. Engineer operations such as bridge building, mine and barrier emplacement or removal are examples that illustrate this point.

When we consider combat operations in a continuous mode, I believe we are facing the most difficult problem area and the area that most spokesmen have in mind when the subject of continuous operations is mentioned. As most of you know, combat operations include the traditional roles of the infantry in offensive, defensive, and patroling operations and the many other functions that the foot soldier performs. It includes the mechanized infantry with its emphasis on vehicles and mobility. Armor operations and all that they imply are very much part of combat operations. Of course, both field artillery and air defense artillery operations are also included in combat operations.

Developments in Army aviation in recent years have provided great strides in mobility. These have had major impact on combat operations. It may well be that these new capabilities open new dimensions for thinking regarding approaches to solution of the problems of operating continuously at relatively constant levels of activity.

Thus, it is my view that we should focus our attention primarily on those tasks performed within the category of combat operations. We should address the toughest and most critical areas first. Continuous operations are no particular problem if you can change shifts, but that's tough to do in combat. In any case, more fundamental knowledge is needed for, at this point in time, we are incapable of stating confidently the appropriate duration of the shift.

Thus, the human endurance and recovery cycle is a subject of cardinal importance. Detailed information is needed relating to types of activity, interactions of work-rest cycles, and the effects of brief sleep. Information is needed concerning performance recovery rates and conditions

facilitating or expediting recovery. Diurnal cycles, alteration thereof, and the nature and shape of adaptation functions need to be explored. Individual differences and the personnel selection approach must be considered. Group reinforcement, group dynamics, intragroup social factors and motivational aspects cannot be ignored.

Both the behavioral and biomedical approaches must be pursued in this field of investigation. A combined or multidisciplinary approach is preferable. In any event, the physiological aspects of the problem are important and an understanding of the physiological and behavioral interdependence in the context of the continuous operations concepts is essential.

In conclusion, I have tried to show why I believe it inappropriate at this time to list highly specific research requirements related to continuous operations and have tried to suggest the factors that are important for determining the most useful directions for research.

## References


1. MacArthur, D. M. "Forecasting Future Military Missions and Their Technological Demands," Defense Industry Bulletin, Oct 69, pp 21-24.

2. Marks, J. W. "Human Factors Support Requirements for Continuous Operations," Proceedings of the 15th Annual US Army Human Factors Research and Development Conference, Nov 69, pp 130-135.

3. Jnpublished remarks by the Chief of Research and Development, Department of the Army, to the American Institute of Aeronautics and Astronautics, 18 Mar 70.

## DISCUSSION SESSION

## JACOB BARBER

CLAY GEORGE: Do we have a cost-benefit analysis of the new night vision gagetry? If we train an infantry unit to a high degree of readiness without night vision devices, can they really be expected to operate less well than a unit that has goggles and thermal viewers, in terms of the extra weight and skills they need to use them?

JACOB L. BARBER: Well, I think we don't yet have that kind of cost-benefit analysis. I think that's a good question; but on the other hand there is also little doubt that these devices are going to be used. Thus the important issues become: what is the proper basis of issue, what is the proper mix, how many men do you equip and with what kind of devices, what is this going to do to our training program? We're certainly going to have to remodel and modify the training program in order to not only adapt people but also to bring about any kind of operational capability using these devices in any kind of situation. I think the best answer is: we are not yet there, but we are beginning to work in the right direction.

BEN B. MORGAN, JR.: Since we are dealing in this conference primarily with research and hopefully the development of technology based on that research, what do you see as the various roles to be played by laboratory research versus the field research that has to be done? What are the contributions of the two requirements as you now see them?

JACOB L. BARBER: One of the purposes of this conference is to provide the answer to your question. At this point I can visualize a full spectrum of research that could be done by universities, non-profit people and in-house laboratories, that runs the gamut from the rather basic and fundamental sorts of things that you folks have been doing, right on through to the management kinds of problems such as how to replace military units in the field. At this point I see some difficulty in keeping research relevant to the continuous operations problem. I feel that the area is so broad that there is a very real danger of including the whole universe of research in it, so that we lose all definition. That is why I have fixed upon certain kinds of activity and operations as being our primary focus. The implication is, of course, that the laboratory research lays the groundwork for field simulation, and that a synthesis of the data from both approaches will permit us to build toward solutions to the problem.

TRENDS IN CURRENT RESEARCH

Louise B. Speck, Ph.D.
USACDC
Concepts and Force Design Group

I am going to tell you about some on-going research which is relevant to the Concept of Continuous Operations. Then I am going to propose a methodological experiment which you may participate in or not as you see fit. Combat Developments Command has an interest in this area as indicated by a study directive issued last week entitled: "Fatigue, Asynchronosis, and Acclimatization in Sustained Tactical Operations." Mr. Barber discussed most of the definitions and the human factors problems involved. It would be premature to discuss the study further at this time, but it is indicative of the concern about the capability of the human being to perform optimally during sustained or continuous operations.

There is an ongoing ARPA program which is closely related entitled "Self-Regulation for Improvement of Individual Performance." The Office of Naval Research serves as agent, and Laverne C. Johnson of the Naval Neuropsychiatric Research Unit is technical monitor. Work began about April 1, 1970 and is expected to continue for 5 years. DOD problems being addressed are field combat, vigilance, education and training, sleep, body temperature and pain control. Work is concentrated on (1) the autonomic nervous system, largely for control of emotional behaviors, (2) those aspects of central nervous system activity related to sensory discrimination, vigilance, learning, (3) induction and increased utilization of sleep.

Work is also being done at various Army Medical Command laboratories such as Walter Reed Army Institute of Research and Army Research Institute of Environmental Medicine (USARIEM). The mission of the latter institute is to conduct basic and applied

research to determine how heat, cold, high terrestrial altitude, and work affects the soldier's life processes, his performance, and his health. ARIEM also operates the Arctic Medical Research Laboratory, Alaska (AMRLA) which primarily conducts research in the areas of cold adaptation, frost bite, and cold stress. The Military Stress Laboratory of ARIEM conducts a program of research on work-rest activity schedules expected in present and future military operations.

Civilian agencies such as the National Institutes of Health (NIH) and in particular the National Institute of Mental Health (NIMH) support large programs in psychopharmacology, psychophysiology, reactions to stress, sleep and its underlying mechanisms, and circadian rhythms. These programs have a broader objective than support of military operations, but much of the data is relevant to DOD needs and should be included in background studies.

Finally I'd like to discuss in some detail the Warren S. McCulloch Memorial Seminars, American Society of Cybernetics, which are scheduled for December 9 & 10 in Washington, D.C. The seminars have a broad scope and are designed as a state of the art review of brain research. Although they are not DOD sponsored, much of the material to be presented has a direct impact on future Army planning.

The seminars on brain research are divided into two major categories: (1) Basic Mechanisms, (2) Clinical Applications. The first category has to do with very fundamental problems. When I am speaking to engineering groups I refer to quality control of the nervous system, the individual problem, what you have to start with. This may sound facetious, but the Army must consider these questions. As a result of selection procedures, will the Army be working with a large population of minimal brain damaged individuals? Depending on the site of the lesion, these people may be emotionally unstable, incapable of making good decisions, incapable of prolonged concentration, hyperactive, or poor learners. What will the impact be on the Army of a large population

of people with minimal brain damage due to malnutrition during development or more severe damage due to passage of drugs across the placenta? Research has shown that it is very unlikely that damage at this level can be repaired by any type of therapy or education. It is not the Army's responsibility to prevent this type of damage, but society's willingness or unwillingness to guarantee the right of an individual to be born capable of developing to his fullest potential will have an impact on that subset of the population represented by the Army.

If one is building a good computer one must have reliable transistors, good power supplies, high quality logic components. Then these must be wired together correctly with good connections, must be tested, and calibrated. In the human being this phase takes place in the first five years of life. Through use and experience the nervous system matures. Circuits and synapses are established. The insulating sheath of the nerves develop. Experimental data in animals has shown that the brains of individuals given the opportunity to explore and participate in social situations weigh more and have enriched synaptic junctions. Today we talk more in terms of networks of interacting circuits rather than centers in the brain. The model has become more stochastic than deterministic. That is, we speak more in terms of variable threshold logic units rather than saying that in response to such and such input, a specified action will be produced.

Very exciting work is being done in the area of biological rhythms but there is a long way to go before we can say these phenomena are understood. In basic systems such as in plants it has been demonstrated that it takes only one exposure to light to entrain the system. No learning period is needed to trigger the activity. This poses a question for human beings. Where do the biological rhythms originate? Is the nervous system entrained by the maternal heartbeat during development? Current research is demonstrating that metabolic factors involving nucleic acids and proteins may be implicated. Evidence also suggests that membrane permeability, electrolyte balance, and other physiological factors

may be involved. Fortunately damage to the system at this stage can be remedied to some extent, but at high cost. Prevention is much cheaper than therapy and special education. It is still too early to say we can alter these rhythms by pharmacological and nutritional means, but this could reasonably be expected at some time in the future. Again, this is not an area of Army responsibility, but the impact on the Army's training requirements of a subset of this population could be considerable. There is a military requirement for rapid transit through time zones, and for high level performance over prolonged periods. From this viewpoint the Army does have to deal with the problem of how best to minimize the effects of disruptions of established rhythms.

Once the quality of the components has been assured and they have been assembled correctly, the computer still has to be programmed. Programming of the nervous system may be thought of as the algebraic sum of all the educational, social and cultural experiences of the life of the individual. Inasmuch as each individual in the Army is a representative of the total population, he has been molded by the experience which have impinged upon him. This higher nervous activity includes long and short term memory, learning, perception, affect, abstract thinking, and decision making. As the development of research instruments has made it possible to learn more and more of these functions, biologists are discovering that more and more of what they previously believed to be true, must be discarded. It is an exciting time for brain researchers as small nuggets of knowledge are discovered: a glimmer of how memories are formed here, insight into how man recognizes patterns there, and perhaps the tiniest hint about how an individual actually learns. There is a long way to go before we can say we truly understand the function of the nervous system.

Perhaps I have overemphasized the nervous system. It was done primarily because of the control the nervous system has over

all the other functional systems. Progress in the understanding of all these systems has been just as exciting and as important to the future of human life. Unfortunately this increased knowledge also carries with it increased responsibility. At no time has the biologist been faced with the ethical problems which confront him today. The capability to modify biological systems constructively is accompanied with the capability to abuse this power with disastrous consequences. More and more biologists are being forced to address the ethical considerations having to do with organ transplants, prolonging of life, modification of genetic material. These problems are being discussed on the national and international level. At present we are constrained as to what can be done to human beings by the Geneva Conventions, Helsinki Declarations, and the Nuremberg Code. We have to face the problem of whether we are ready to make the improvement of the health and education of our human resources a national goal, and to consider the impact of that decision on the future of the nation.

I prepared some forms which the group might like to use in a modified Delphi. When I am working on a complex problem I frequently like to work out something called a morphological analysis. I make a matrix of all the possible ways to achieve a goal such as improvement of human performance, and all the possible means I can think of to carry out the "ways". And then, on the basis of my knowledge, I try to formulate the feasibility of each possibility. I have made thirty copies of these. If you would like to play this game, don't discuss the choices you mark with anyone. I will collect them at the end of the conference and will let you know the results.

The results of the Mini Delphi were as follows:

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| | 1. | Effective Management - 5 |
| | 2. | Effective Job Structure - 4 |
| BEST WAYS TO IMPROVE | 3. | Improved Morale - 3 |
| HUMAN PERFORMANCE | 4. | (Improved Motivation - 2 |
| | | (Selection for Aptitudes - 2 |

| | | |
|---|---|---|
| | 5. | (Training (Preconditioning)) - 1<br>(Effective Human Factors<br>(Engineering - 1 |
| BEST MEANS TO ACHIEVE OBJECTIVES | 1. | (Rotation - work/rest cycles - 4<br>(Manipulation biological<br>(rhythms - 4 |
| RESEARCH NEEDED | 2. | Computer Assistance - 3 |
| | 3. | (Operant Conditioning - 2<br>(Logistics - 2 |
| | | (Metabolic Conditioning - 1<br>(Physical Conditioning - 1<br>(Immunological Conditioning - 1 |

Three people estimated time when the objectives could be achieved. All were in 71-80 time frame.

There was not sufficient time for any reiterations.

METHODS TO IMPROVE HUMAN PERFORMANCE IN SUSTAINED OPERATIONS

| | Preconditioning | Environmental Control | Improved Health Status | Improved Morale | Improved Motivation | Selection for Aptitudes | Effective Job Structure | Effective Management | Therapy | Effective Human Factors Engineering |
|---|---|---|---|---|---|---|---|---|---|---|
| Protective Clothing | | | | | | | | | | |
| Shelters | | | | | | | | | | |
| Drugs | | | | | | | | | | |
| Computer Assistance | | | | | | | | | | |
| Operant Conditioning | | | | | | | | | | |
| Classical Conditioning | | | | | | | | | | |
| Metabolic Conditioning | | | | | | | | | | |
| Physical Conditioning | | | | | | | | | | |
| Immunological Conditioning | | | | | | | | | | |
| Electrical Stimulation | | | | | | | | | | |
| Nutrition | | | | | | | | | | |
| Rotation of Work Cycle | | | | | | | | | | |
| Manipulation of Biological Rhythms | | | | | | | | | | |
| Logistics | | | | | | | | | | |

DISCUSSION SESSION

LOUISE B. SPECK

JAMES H. BANKS: Are there any differences between the two categories used in your table? Is one "techniques" and the other "applications?"

LOUISE B. SPECK: Yes. For instance: selection for aptitude, job structure, management, therapy, effect of human factors engineering would be one type of category. On the left side we have, more or less, how these might be influenced. Preconditioning, for example, would include training and education. Environmental control needs to be considered. I would hope that human factors engineering principles would be utilized so we would not have to have a person with eyes 12 feet apart to operate equipment. A lot has been said about electroencephalography (EEG). Unfortunately, I think a lot of people have an oversimplified viewpoint on this. If anybody is going to be working in this area, I would certainly strongly recommend that they have a good electrical engineer on their team. There is no point in doing a very elegant analysis on poor data. This is an area in which the biologist can really fall down.

JAMES H. BANKS: Would you walk us through preconditioning?

LOUISE B. SPECK: For instance, this would really be training. One could be trained in the use of protective clothing. Why do you have it? How do you use it properly? How to get used to carrying it around and getting into it at the proper time? Shelters, for example, if you are going to work in a dangerous environment with exposure to radiation or toxic chemicals. Drugs, what can you do with them? Right now there is a good deal of research in this area. All drugs have side effects. Some drugs which were formerly thought to be wonderful for making people sleep have been shown to alter their dreaming cycles. I don't see in the near future that we are going to have an effective sleep-inducing drug with no side effects. Computer assistance: what can we do with computer simulation? What about computer-aided instruction? Operant conditioning: this is, of course, instrumental conditioning either using reward or punishment to train people to perform in some desired fashion. Classical conditioning is more of the Pavlovian type. Metabolic conditioning: I put that in because of the demonstration that physiological metabolism is involved in biological rhythms and in the fatigue process. It's wide open. We really don't have a firm grasp on what's going on. There are a lot of very exciting developments coming along, but right now we can't say feed the person this or that and he will be able to function for long periods of time. Physical conditioning: we are all aware of this. Immunological conditioning: preventive medicine, for instance. What can you give in the way of a vaccine that

would protect a person against disease? Electrical stimulation: there is a lot of work going on here. It ranges from implanted electrodes in which behavior can actually be controlled in the laboratory animals (e.g., Delgado's work on controlling agression and affect) to controlling human behavior through the presentation of lights or tones. Nutrition: This gets back to the metabolic cycle as it is influenced by food. Rotation: this means work/rest cycles. How long can people function optimally before they should be replaced? Or shifted to another activity? Manipulation of biological rhythms: I don't know when it will be possible to solve the problem of passing through time zones quickly with the resulting disruption of circadian rhythms. Perhaps this can be done metabolically, by pharmacological treatment, feedback, or structure of the job.

JAMES H. BANKS: What you have done here will show very nicely the complexity of the problem. These factors interact with one another to such an extent that I think this is going to be one of the results of the conference. We very rapidly come to the conclusion that you can't work on any of these things by themselves: it will have to be a very complex multivariate approach to solving complex problem areas. You have shown here the many factors which interact, from the clothing and facilities, to learning, to the biological rhythms, etc.

BEN B. MORGAN, JR.: I agree with Dr. Banks that you have provided a service here and that you listed for us the range of factors that influence human performance and human capability with regard to continuous operations. I object a little to the heading "Methods to Improve Human Performance." We may be getting a bit ahead of ourselves. When you say "to improve performance" you are assuming that it needs improvement and I don't think that we have really established that.

LOUISE B. SPECK: This is exactly the kind of comment that I was hoping would emerge. I would like to talk about how these factors could be improved. Is a person operating maximally after a long session of looking at a very monotonous display? At the crucial moment does he miss the most important information that comes along? We have some knowledge about how to overcome this.

REX DAVIS: This is a problem area that we have been working on. It is amazing that there is little or no degradation in most activities as long as the soldiers are motivated. I am sure that it comes as no surprise to anyone that soldiers can go for long periods of time under extreme conditions and continue to perform their jobs. You don't need research to demonstrate that. It's been demonstrated over and over again. Is there really a problem in continuous military operations; is there a research problem? We know that they can do it; we know that they do it frequently. I'm just throwing the question out, I don't have an answer for it. Is this actually a problem area or is it something that is spinning our wheels?

CHARLES G. HALCOMB: Is this a pseudo problem that we find in the laboratory or even in the field where people would not be optimally motivated, and not at all a problem for a person who is under actual combat conditions? I think it is clear that the performance decrement is much less likely to occur in a real situation than in the laboratory.

JAMES H. BANKS: It's very hard to get degradation in performance in real field situations and in combat operations.

BEN B. MORGAN, JR.: We obviously get degradation in continuous performance in the laboratory. There must be something different operating in field situations which accounts for the general lack of degraded performance.

JERRY D. RAMSEY: Perhaps it relates to the element of duration. The motivational factor can dominate for a good while. I think that when fatigue, environmental stressors, and emotional factors start compounding then perhaps performance will start tapering off regardless of the motivation.

LOUISE B. SPECK: What happens when the emergency situation is over and the activity should cease and it doesn't?

BEN B. MORGAN, JR.: Another factor is: what are the total costs to the human in going for a period of time maintaining continuous operations without or even with performance decrement. How much recovery or what are the recovery functions involved; both in terms of performance and perhaps health, emotional and physical factors that might need to be considered?

CHARLES G. HALCOMB: Then it is also probably true that understanding the conditions and the variables that relate to the decrements in the laboratory which may not occur in field operations may give a clue as to the kind of cost, the kinds of ways to minimize the cost, and the way to shorten the recovery period.

LOUISE B. SPECK: In doing some of our basic research in patients using evoked responses we discovered that there were differences in recovery of the responses and that there did seem to be decrement in some people in this area. For instance, various categories of mental patients seem to be capable of returning to normal function but it takes them much longer. I think that the understanding of how long it takes to recover a function is a very important thing. This might be one of the areas in which investigations would be worthwhile.

CLAY GEORGE: I might comment on the improved morale item. I find that doing research in this field is very frustrating because you don't have any way to implement output from this kind of research into operations except by telling the commander. I think one very large area is improving health status and

nutrition. Everything else is pure pressure from your colleagues whom you respect, and this also keeps you motivated and working because "I can't let Joe down." This is what many military historians believe keeps troops going in incredible situations. I think this is the major area where we are not getting any good research input.

RICHARD CARLSON: I would like to make a general comment regarding your category of drugs as a means of manipulating behavior. I get the impression that there are a lot of hangups in the area that are preventing a solution. In terms of psychoactive drugs there is a general feeling that you can't really accomplish much because you are going to pay for it somewhere else. You mentioned the use of barbiturate to alter the sleep cycle and thus down the rapid eye movement (REM) portion of sleep. Rather than saying the drugs aren't doing what we wanted them to, we realized there are conditioning problems with the REM. How can we train the person to REM or what other drugs can we administer in order to preserve this REM? Another hangup seems to be insistence on animal subjects instead of humans for drug research.

LOUISE B. SPECK: At NIMH there was a great deal of emphasis on drug research. There has to be a very large animal work foundation before you can use drugs on human beings. For ethical reasons, for instance, you cannot do harm to a human being. I don't want to be responsible for the dealth of even one person, even accidentally.

RICHARD CARLSON: Yes, I would certainly agree with that, but it is something different between saying we don't want to use a particular drug on human beings at this stage of our research, and saying that we aren't ever going to find a drug that is going to be able to derive the benefits that we want and get around some of the undesirable side effects. Those are two different types of questions and I would say that one of them is a hangup and the other one is certainly ethically valid and we would all agree with it.

LOUISE B. SPECK: NIMH has large clinical studies going on with hospitals in this and other countries. Work is going on in Yugoslavia, Greece, Sweden, and Great Britain which is coordinated: all are trying to come up with some assessment as to whether the drugs are effective or not. So there is a large body of information which has been accumulated within an ethical and medical context. It is very tightly restricted, and I'm glad that it is. There are large studies being done in humans and there are some very interesting things coming out of all this. One is the catecholamine concept of depressive illnesses. Unfortunately, the tranquilizers have kind of spun out so we no longer expect high payoffs. We have gotten into the sort of thing in which they are altering this group on the molecule and that group on the molecule and the payoff is not very large when you look at

the data. Remember that for drugs to be effective they have to be some kind of "poison," they must be affecting some part of the biological system for them to be effective.

RICHARD CARLSON: I challenge the statement that drugs have to be a poison in order to be effective. I would suggest an obvious example: insulin. You can administer insulin to a person who needs it and it changes his behavior. So insulin isn't a poison for that person.

LOUISE B. SPECK: You can kill a person with insulin.

RICHARD CARLSON: Well, you can kill a person with water, too.

LOUISE B. SPECK: You have got to draw the limit somewhere.

RICHARD CARLSON: I'm not arguing with what you say, but rather with what seems to be implied in remarks when you say every drug is a poison.

LOUISE B. SPECK: This, of course, is an over-simplification. There are limits and the limit for effectiveness and the limit for lethality hopefully are widely separated in order to have both safe and effective drugs. As a person who once calculated the human dose from animal data and then took the first dose, I can tell you that it is a very nerve-wracking experience! This is possibly one of the weakest places in drug research: making the awful, terrifying leap from animal to human data, and somewhere along the line it happens. It's a terrifying leap for an investigator and you don't like to be the one involved.

REX DAVIS: I am a physician, and as a physician I think drugs should only be used to combat diseases. Besides the side effects you want to remember the individual variations that we have with drugs. I think if you tried to control the troops with drugs the individual variations would be fantastic.

UNIVERSITY INTERDISCIPLINARY RESEARCH PANEL

J. Knox Jones, Dean, Graduate School
Lawrence L. Graves, Dean, College of Arts & Sciences
John R. Bradford, Dean, College of Engineering
Texas Tech University, Lubbock, Texas

J. KNOX JONES: The Graduate Dean talking about research is a little bit like the President of the United States talking about justice and motherhood. Research is an integral part, of course, of all graduate studies. I feel in a way a little humble because on my immediate left is Dean Graves, who has had the distinction of being Dean of the Graduate School here at Tech, and on my far left is Dr. John Bradford, who has had a very successful graduate program in the College of Engineering for a number of years. I have been here only since July 1, 1971, so unencumbered by historic and factual matters dealing with graduate education at Tech. I can talk with a bit of flare, perhaps, about some of the things I think we ought to be involved in. Certainly, the aim of the Graduate School in education is essentially that of the University itself--teaching, research, and public service--and I put research in the middle because it contributes so much to teaching, on one hand, in terms of training people and educating them to be good teachers, and to a public service operation on the other hand. One of our main goals, I think, in terms of our graduate program will be to increase interest and support in broad-scale interdisciplinary research projects. One of these certainly is the THEMIS Project and the type of thing that it generates. I understand that five Departments of four different Colleges have been involved in the THEMIS work and that it has provided research assistantships, which, of course, we encourage for our graduate students, for some 50 students and has resulted in five Ph.D. dissertations and 10 Master's theses to date. This is exactly the kind of involvement that we hope to generate in interdisciplinary studies. We talked this past week, for example, about the establishment on the campus of an interdisciplinary program in environmental

studies that will have a number of component parts, and we expect this environmental program to extend into engineering, agricultural, arts and sciences, and other colleges in the University. It also will include behavioral studies by sociologists and psychologists, and I think this is the sort of thing that any University of this size should actively be involved in developing. We have appointed an interdepartmental committee to guide the development of environmental studies, which will be one of several trusts that we will have in the very near future of the major interdisciplinary sort.

Let me give you just a few facts about the growth of the graduate program at this institution, which I think will stress better than any other way the involvement and the commitment of the institution to graduate studies. Ten years ago we had 37 Master's programs and 5 Ph.D. programs. Five years ago we had 44 Master's degrees and 19 at the Ph.D. level. Today we have 58 Master's programs and 26 for the Ph.D. Ten years ago we had 574 students enrolled in the fall term in graduate school. Five years ago we had 1583 students enrolled in the fall term in graduate school. This fall we had an excess of 2800. I think this says in a very real way what the University is doing in terms of committing its resources to graduate education and a sizeable chunk of those resources are committed to interdisciplinary programs such as the THEMIS project. Am I right that the THEMIS project has received a substantial amount of State support? So that we are not begging our entire support program but trying to match existing State and other resources. I just calculated the other day that in the five-year period 1961 to 1965, Tech produced 70 Ph.D. dissertations and 471 Master's theses. In the five-year period just past, we had 250 Ph.D. dissertations and 1070 Master's theses. Here, again, is the measure of our growth and development. I suppose its almost axiomatic that there is a strong connection between the academic operation of an institution of this sort and its research base. The two are so closely linked that there is no real point in

belaboring that subject. If there is one point I would bring home, it is that we strongly support research programs in terms of graduate studies and regard this involvement as an integral part of graduate work. We also encourage, and at the doctoral level require, a substantial research commitment on the part of the student. This program, like the THEMIS operation, has allowed us to make a substantial contribution in the research area along with the academic progress of our graduate students. We are very much in favor of these programs and I think our support of them has been amply rewarded.

LAWRENCE L. GRAVES: My field is social history and for the past year and a half I have been at work on a history of the university in which I am trying to relate it to the needs and interests of the people of the region. Essentially, we have Texas Tech here because the people of this region wanted a college and fought long and hard to get it. When I came in the fall of 1955, it was to an essentially undergraduate institution. It had the elements of a university without medical and law schools, but it was essentially geared to the needs of a quite provincial population, both students and people of the region. During the 16 years I have been here, I have seen the institution develop into a true university, one that I believe is on the threshold of becoming much better than we have any right to expect for this region of the country.

Dr. Jones has noted that we have a going graduate program and it is true that we have changed from a primary emphasis on undergraduate teaching to a more balanced program stressing both sound undergraduate training and graduate instruction. We don't underestimate the value of our undergraduate programs because they lie at the heart of any university. In the past decade and a half I have seen a rather startling development in the research capabilities of our faculty with greater and greater emphasis being placed on bringing to the campus and rewarding research-oriented faculty members. Beginning in the

mid-sixties we began to get state appropriated research money and federal grants began to become available. We really went after research-oriented people and grants and have received an increasing number of them. I think that we are now on a plateau; I believe that the coming of the Medical School is going to do a great deal to improve the intellectual environment of this whole academic community. Inevitably there will be a great deal of research involved with medicine and the allied health professions which will involve all of the colleges on the campus. One of the central facets of our thinking has been the interdependence of the university with the medical school. It seems to me that this is going to benefit us all the way around and that the beginnings that we have made in cross-disciplinary work are going to be extended tremendously. We have discussed interdisciplinary appointments and joint appointments between medical school and the rest of the university and at least one has already been made, with others in the offering. Medical schools are often isolated from their universities, even when they are in the same city. We hope to avoid this and to share our facilities and our strengths. One of the features about Lubbock is the friendliness of its people. It is hard to explain but visitors often notice it and faculty members who move to other universities sometimes remark that they sense a lack of this spirit. I suppose we ought not to overemphasize it, but it exists. Perhaps it is our isolation; we are thrown more together than we might be in a larger city. At any rate it has been one of the factors which has encouraged the breaking across of strict departmental lines. We are so new as an institution that we really haven't learned how to be departmentalized and to build empires in each particular department. I think our youth has been a help to us here so it was easy for THEMIS to involve people from various departments. As Dr. Jones has said, we are committed to this and I don't believe the trend will be reversed. We wouldn't want to if we could. We are trying to use our funds to support those people who are

interested in interdisciplinary research. Through the years I have been hopeful that our research capability would continue to develop, and I believe it has. I am hopeful that further opportunities lie ahead of us and that we will take advantage of them.

JOHN R. BRADFORD: In glancing over the program, I notice that our university and our town are described as being oriented toward interdisciplinary research. I take it that the reason for my presence, then, is to lend this interdisciplinary aspect to our meeting.

Dr. Jones has already mentioned the three principle objectives of any university: teaching, research, public service. Expanding this a bit, it can be said that teaching is the dissemination of knowledge; research the expansion of that knowledge; and public service the application of it. Of course it is in this latter sector that we feel that the College of Engineering really can come to grips with many of the problems of the region, state and Nation.

We feel that the promotion of interdisciplinary activities is highly desirable. In fact, we have thought so for years. The first doctoral program which we took to the administration for approval was an interdisciplinary one. So we have had, for quite a while, a program in which a student's efforts are applied to three principle areas, rather than to a specific major and specific minors. These divisions of study are broad-scope types, such as biomechanics or communications, which cut across departmental boundaries. The program has met with considerable approval and significant numbers of students are endeavoring to take advantage of its potentialties.

Of course this procedure of cutting across departmental boundaries always engenders problems. For one thing, there is the problem of a limited amount of money which can be spent for capital equipment. The inescapable conclusion, therefore, is that we must share some facilities. But here you immediately

crash into an almost impregnable departmental barrier. The nature of this barrier was illustrated very well last year when I chaired a panel at the National Conference on Administration of Research. That barrier has four facets: budgeting, facilities, curricula, and promotions. As you can see, these comprise just about all of the major influences impinging upon any type of study or teaching activity within a university and within a department.

If your budgeting situations compare with the one here at Tech, examination discloses that, speaking figuratively, you have as a money source a roll-top desk with a number of neat pigeonholes, each of which is meticulously filled for a certain purpose. And there is no way that you can fit a single entity into two separate pigeonholes at the same time. Budgeting problems also contribute to or aggravate other problems.

I'm sure you have instances such as the following: Professor X wishes to do some interdisciplinary research, but the facilities which he will need are in the possession of another department. He finds that he cannot use these facilities, because the people in that department don't have anyone working in this particular area of research; and they aren't about to let anyone from another, even a related area, use their special facilities. Or suppose they do have someone pursuing some aspect of such a study. They are certainly not going to relinquish any of the man hours and/or money funded for their particular project to an outsider. If you want to end up with a "man without a country" just put him in two departments. Neither departmental chairman wants him. He's a traitor. So the miserable guy winds up with no consideration from anyone--a virtual pariah.

If I seem to have made a pretty good case against the ability to establish any kind of interdisciplinary research, it's because this really is the situation as discovered by many faculty members who have attempted to override the barriers described.

Yet, to put some heart back into the matter, interdisciplinary research does take place. It is very interesting to note that a couple of universities with the width of the entire continent between them have developed a strikingly parallel modus operandi. In each case, one individual has appeared who has seemed utterly unaware that there are certain things you can't do. So in this state of liberating ignorance he simply goes ahead and does it. This is the individualistic guy I refer to as the entrepreneur. He forgets to talk to the departmental chairman before bumbling over to an alien department and talking to some members of the faculty there. Worry about the budgeting process is as absent as in any Freshman's fuddled thoughts. So he says, with arresting directness, that he has a student who would like to take a course in this department, and to keep things nice and simple curriculum-wise, our entrepreneur will just give credit in the course he himself is teaching. There, as you see, he has gotten around, in one academic and political slalom, the chairman of his department, the dean of his college, and has arrived at the golden gate of the governmental agency, where the glad cry goes up: "Great, you're funded!"

The thing that we're actually trying to do, in a subtle kind of way, is to encourage such freewheeling individualists in such little strokes of genius. And after visiting this meeting last year, I talked to our administration here and found that in a general way there is an attitude which contributes encouragement to such characters, in that it appears not to make any great difference where a piece of interdisciplinary research is administered. That part is more or less immaterial. This being the case, however, we have to identify an advocate for the Program's case in court, as it were, so we designate the department which the entrepreneur and his research student normally call Home. Then the dean of that college becomes responsible for carrying out the administrative paperwork necessary to that particular type of project. We feel that by

allowing this sort of development we end up with the salutary result of having encouraged both the entrepreneur and interdisciplinary research.

To become just a little bit personal: I've been on a number of campuses, and I've seen a lot of deans who didn't even speak to each other. One of the truly fortunate aspects of my many years on this campus is that this is probably one of the most closely knit groups of all those involving academic deans. There has never been a time, that I can remember, when these deans have been at cross-purposes. I think, this relates to the concept that Dean Graves describes concerning the desire to accomplish certain things on-campus.

Unfortunately the ivy on our buildings is not yet luxuriant enough to mask a lot of tradition that got built into the woodwork and which there is no way of eliminating. But by the same token we are also too young for these to have burgeoned into proportions which would be insurmountable. I think that it is for this reason that we have been able to get into some research efforts and do some things that we wouldn't have been able to accomplish had we been trying them at other institutions. I think that all in all we have a rather good program going on here on this campus. We're working on obtaining some additional funds and are hopeful that these will materialize.

Let me say in conclusion that if there is anything in my remarks which anyone would feel is worth repeating, I should hope that it might be this business of patting the entrepreneur on the back and encouraging him. He's the salmon that swims upstream. In developing a program, he defies all the odds stacked against him, partly because in his singleminded purposefulness he doesn't know they're there, or that he has brushed aside hallowed procedures. This is the kind of thing I lik. to see--the kind of thing Dean Jones has been encouraging. He'll probably get kicked out of the Graduate Deans' Union before he's through because he has had the temerity to suggest that when we go, eventually, to a five-year Engineering Program leading to a Master's Degree,

we in Engineering should administer this professional degree. That would literally be turning the whole thing over to the College of Engineering. This is not the way graduate deans normally operate.

I encourage you to look into this interdisciplinary concept which we have tried to put together here, and see if you don't find something worthwhile.

J. KNOX JONES: In thinking about the way in which we would like to see some of the graduate programs administered, I might point out that one of our aims, and I'm not sure as to how we are going to accomplish this yet, is to institute enough flexability in graduate studies so that individual programs can be tailored to specific students. I think this will pose no real problem at the graduate level because if we have enough people like Dr. Bradford and his group and Dr. Graves and his group who are interested in cross-fertilization, if you want to call it that. One thing that concerns me about this whole business, however, is a problem to which we must give considerable thought--namely, that if we intend to create at the graduate level truly interdisciplinary programs, we must do something at the undergraduate level as well and I'm not exactly sure what we should do. One thing that occurs to me is to encourage departmental leaders to require of their students, as a basic requirement, only those courses that are absolutely needed to go on to graduate work in that area and then allow them to take either more psychology, more biology, etc. or allow them to spread out and get a number of what we might call leveling courses in other disciplines. In other words, to become involved in a number of related disciplinary regimes. One other possibility in this regard is to encourage departments and programs to forget about the problem of prerequisites at the graduate level in a sense and teach a high-quality introductory course to graduate students from other disciplines. This would be one way in which we could encourage the growth and development of this kind of program. It seems to

me that we are going to have to do one or both of these if we are ever going to become truly interdisciplinary in allowing students to take advantage of what I think would be a substantial body of related knowledge in areas in which we would like to have them trained. If we continue to narrowly train students as undergraduates, we will continue to have a problem at the graduate level in relating to them the opportunity to become interdisciplinary in their approach. I would like to get away, for example, unless its appropriate for the students own aims and desires, from a formal minor at the graduate level. Rather, we should require that a certain number of hours be taken outside the department or the degree program. Let the student take these hours in the places relating to his own educational desires and those of his committee in terms of where they want him to go. These are things we are considering and we hope in coming years to rearrange the structure of our graduate programs to allow, not to require, this kind of approach to graduate education. I would like to hear your response, Dr. Graves, if you think this is a vital structure in terms of the Arts and Sciences Departments.

LAWRENCE L. GRAVES: Undoubtedly, I think along the same lines and I have thought for a long time that we ought to try to restrict the subjects required of an undergraduate to the minimum necessary for his development. Rather than putting him in a straitjacket we ought to tailor a program to fit him. He might want a narrow specialization in a particular discipline, but then again he might very well want a broader field, or even a group of related subjects. In Arts and Sciences we are attempting to make our programs more flexible through minor programs in such areas as ethnic studies, urban studies, and Latin American area studies. We are proceeding rather slowly in order to be certain of the need for such changes. If the demand exists for more broadly-based programs, and I believe it does, then we can go ahead. I think that you are absolutely right: narrow specialization is a thing of the past, and we are just reflecting what's

happening in higher education generally by making the changes we have been.

J. KNOX JONES: Have you noticed any reluctance in your Engineering Departments to give way a little bit on requirements at the borders and allow for more cross-fertilization?

JOHN R. BRADFORD: I think our Engineering Departments have always had a fairly good interrelationship. They are by their very nature interrelated. Any undergraduate curriculum will include Civil, Electrical, etc., regardless of specialization. So we have this to cope with to some degree. Our big problem, however, is the accreditation standards that pretty well force us into a fairly rigid and strict fulfilling of the number of hours in certain types of subjects. We have an additional complication in Texas, because of the part played by the humanities. Twelve hours in this sector, six of Government, six of History, are required by State law. E.C.P.D. has gone along with this because there is nothing we can do about it; however, it means that we have considerable less flexibility at the undergraduate level than we should like. At the graduate level I think we have almost maximum flexibility, depending upon the particular student and department. I see this interdisciplinary approach developing and becoming very strong in the Engineering curriculum within, I should think, the next d de. It's somewhat ironic when you stop to think that probably 1970 was really the year in which we saw the general setting of policies in Washington, D.C., being based more upon college opinion, that is, the yelling minority group, and all of the various ecological types preoccupied with the popular problems of environment, etc. At the same time this was going on we saw an antitechnology movement in the United States. Technology became the culprit for all our ills and all of the Nation's problems. I certainly cannot agree that technology is to blame for all these. We are seeing more and more applied research figuring in attempts to rectify the ills of our

nation. We are seeing a greater emphasis upon applied technological research efforts than upon basic research in the face of great reluctance on the part of the general public to accept anything of a technological nature as desirable. So in our dilema we try to explain why we are doing certain kinds of research, to justify ourselves, and to get around this anti-technology kick that the Nation has gone on. All the time we realize that only through applied technology, or research in applied technology, can many of these problems be solved.

J. KNOX JONES: Up until a few months ago, I was a practicing biologist and I hope that sometime in the relatively near future I am practicing again. One of the things that has impressed me, on the other side of the coin, is the fact that most fund-granting units, whether they be State or Federal agencies of whatever, are beginning to ask questions about the relevancy of research in terms of society needs. I'm not sure that I totally support that view becuase I know of so much basic research that later (and unknowingly at the time) lead to a good deal of useful information in areas that could then be called applied. I think we are being called upon to justify more and more of our research efforts in terms of how they will apply to the needs of the country and the needs of the whole world in some instances. This is a trend that we will see develop even more thoroughly before the pendulum swings back a little bit and I would like to see it swing back so that we have some kind of balance between what we might call applied research, on one hand, and basic research on the other hand.

## DISCUSSION SESSION

## UNIVERSITY INTERDISCIPLINARY RESEARCH PANEL

BEN B. MORGAN, JR.: I would like to come back to something Dean Bradford said as he broadly defined one area of university endeavor: "public service" as being application of knowledge. I assume that you would include support to the various Services in the Department of Defense. You also mentioned applied research. I am finding increasingly that researchers who are doing research for DOD are finding more and more the need to see the application of various research results. I wonder if there is anything the university can do to help facilitate or speed up the application of research findings.

JOHN R. BRADFORD: In the facility in which we are now located, the Textile Research Center, which falls under my jurisdiction, we are offered a particular challenge within the framework of our textile research program and arising out of the cotton and mohair industry of Texas. I think some of the things that we have come up with in that program are certainly applicable. In fact I've seen them applied in other locations. As soon as you come up with some research results which you feel may be applicable to a certain problem, or a certain area of interest, I think you are ready to send some of your people to talk to the agency people. I know we have done this as part of our work in textile research. We have, also, a publication that is put out in pretty much lay terms. Let me explain to you the basis on which we write this. We send out a publication four times a year called "Textile Topics." We send it to mill people, overseas research institutions, and so on. But the actual editorial development of "Textile Topics" is based upon selling one type of individual and one type only: our State legislators. We feel that if a legislator, who voted against us everytime, doesn't understand it, then we really haven't done any good. So instead of taking a broad-brush approach, or using a shotgun and trying to get everybody concerned, I think that you will do better to find out who is most likely to be interested, and take results of your research in a particular project to him. In short, use a rifle approach. Go after particular people or groups, and see if you can't get results, and get them sooner.

J. KNOX JONES: What's the basic problem in continuing education? Is it that of making the results of applied research uniformly available to potential users or is it to discover a user and convince him that the results of the research are useful, or is it a combination?

BEN B. MORGAN, JR.: It is probably a combination of a lack of communication between the user and the researcher. I think that often the user doesn't make his needs clear enough, and I think

that's one thing we are shooting for in this particular conference: to make the needs a little more clear with regard to continuous operations. So this is a step in the right direction in that regard. I also think that the researcher has not felt a responsibility for taking his results and saying this answers a particular need that you have and let's see if we can take the particular research that I've done and push it through development to the point where we have some technology that applies to whatever you are dealing with.

R. A. DUDEK: Further to what the university can do. The university community could change some of its rules and regulations governing faculty. Graduate schools sometimes count numbers of publications before they put a faculty member on the graduate faculty, and they judge the article as having to be in a very professional journal. The pscyhologists must have a certain number in psychological journals and they write in terms of "Ss" and "REM" and the psychologists understand it very well. But they never bother to publish this in the Business Automation magazine or Factory Management even though it relates to personnel selection. Those aren't "learned" publications. The people "out there" who are going to use what we develop are not going to read Engineering Psychology! I can look at industrial engineering the same way, and I think that part of it is just the way the system operates. It has to be looked at if we are going to accomplish some of these things and I think this is where the university has to look at itself.

LAWRENCE L. GRAVES: Along this same line Dr. Bradford pointed out that compartmentalization of the university creates problems in at least three areas, and he suggested an entrepreneur as a solution for parts of this. What will happen though, as someone has mentioned, is that gradually this interdisciplinary flavor is going to filter down to the students and often filter up to the faculty. I'm just wondering in what ways the university is going to cope with the truly interdisciplinary faculty member. If we get people to become interdisciplinary researchers, are they going to find a home in the university, or is our compartmentalized structure going to create a very functional engineer, etc., who doesn't fit into our university structure?

J. KNOX JONES: Of course, there are several ways to resolve that problem. One is the concept of "area studies" as opposed to departmentalized smaller units where the professor is purely judged by a selection of people across an area in which he could participate. Another is the concept of the University Professor: where the guy is just a professor in the university. We don't have any of these yet at Texas Tech, and I don't know how widely this concept has been used around the country, but it is interesting. (We have what we call "Horn Professors" at this University; this would be a start if we wanted to.) The guy has a university appointment; he is responsible to central administration as a professor in the university without

departmental assignment. He would be free to take on students at the graduate level and participate in undergraduate teaching in any area in which he is competent and in which his contribution is desired. I'm not sure how we are going net at this, but I think we are taking some of the initial st ps no. It is true that there is no method in this University or cros appointments in which people are paid by two di ferent un ts. There is a method of cross appointments in which you are aid from one and participate in the activities of another , and we are using this now in our interdisciplinary stud...s, and I think it's working out reasonably well. It has to h ve the permission if not the connivance of all the administration responsible for the promotion, tenure and salary of the people involved.

LAWRENCE L. GRAVES: There is an easy way of handling that; when a person is working in two different areas he will spend more time in one than the other. The one who has the majority appointment is responsible for caring for him, promoting him, and rewarding him.

J. KNOX JONES: But will they really reward him?

LAWRENCE L. GRAVES: I think it's the attitude that hasn't been mentioned here; the attitude must be that this is something we want and simply have to do. If we are going to progress we can't do it any other way. And the attitude is there.

JOHN R. BRADFORD: The only real answer to the question is that as the faculty develops and becomes more interdisciplinary we can only pray and hope that the administration and deans will develop with them!

R. A. DUDEK: I ask d the question because I know psychologists who have taken appointments in my area in a college of engineering jointly with the psychology department and they had hard times because, as you say, they are people with a country. They get into the question of a differential in salary between engineering and psychology, and they get into the thing that psychologists don't like them because after all they're messing around with things that aren't relevant. The engineers don't like them because they aren't engineers. They are people without a country, yet they are very productive, capable people that really should choose and get out of one--either become engineers or withdraw and become psychologists.

LAWRENCE L. GRAVES: Do you remember what J.T. Morgan said about Ruth? "The thing I like about Ruth is he tells me how to do the things I want to do, rather than telling me why I can't do what I want to do." What we need is people to tell us how to do what we want to do.

R. A. DUDEK: So far we have heard only from university-affiliated individuals. I'd like to ask some of you users of research information, researchers in other areas. We have several non-university administrators here; what are your attitudes? Do universitites react to your problems and do they serve your needs, and how could we serve them better?

LOUISE B. SPECK: I come in contact with researchers. There's a lot of comment about this feeling of being put upon for having to direct a research program in a specific way. National Institutes of Health, of course, expect their research to help further medicine in some way. They don't have too many specific requirements on what is done, but you do have to sell yourself and your projects to NIH. There is a lot of stiff competition in that group. I don't have any trouble with the military requirements, but DOD is interested in military operations. National Science Foundation works in wide areas of more generalized basic research. I think you do have to look at whom you want to sell your programs.

J. KNOX JONES: In generating a certain proposal from the organization's point of view, we define the desired results not in terms of scientific or applied information, but the dissemination of information from the research that will take place. It's specifically spelled out how it's to be done. For example, if you went to him with the information available at a semi-technical level for use by a number of people that may be interested at the user level, it seems to me that this ought to be part of the package. I mean I myself have held DOD grants and I have supplied them with 40 or 50 published papers that have been deposited in DDC in Alexandria, Virginia. It's available for use by anybody in the military who wants it, but what I was doing was not the sort of thing necessarily published in a technical paper. It seems to me that in most research projects the methodology employed and governed by the contract determines what is to be produced by the researcher. It's bound to produce at the end a semi-technical unit that can be used broadly. It seems to me that this would be one way of assuring that the user gets the kind of information he needs. Most researchers, left to their own devices, are content to do the basic or applied research at the level of their own interest and let somebody else dig out the parts that may be applicable at some other time in some other area.

DAVID C. HODGE: I should like to inject a few thought at this point. I maintain that a significant portion of this problem of universities trying to conduct research for Army users results from a lack of communication. As Dr. Jones has indicated, unless the researcher is required by the terms of his contract to relate his data to the user's needs he just won't do it. All of the Project THEMIS contracts (such as the one which is supporting this conference) include a requirement for "coupling" the output to

the user's applications. But even though specific suggestions are made about how contractors might do this, the degree of success varies widely in the population. Some of the THEMIS contractors have been highly successful in translating their data into practical application, while others have been more or less ineffective in this area. In my judgement, there are three keys to effective coupling of any research to Army problems. First, you must have a product to sell. Second, you must be aggressive about selling it. And third, you absolutely must talk the user's language and preferably face-to-face.

The requirement for a salable product is pretty obvious, except that sometimes researchers seem to have delusions of grandeur about the worth of their product.

An aggressive, tenacious approach in salesmanship is required. A young man in my Sunday School class formerly sold Campbell soups and STP, and now he owns his own import-export business. He tells me that more than 85 percent of sales (of merchandise) require five calls on the prospect, and that more than half the "Salesmen" give up after only two calls. This results in about 15 percent of the salesmen selling 90 percent of the merchandise. In this day and time the old adage about the man with a better mousetrap doesn't necessarily hold. If you want to sell a proposal, or an application of data (that "better mousetrap") you have to be agressive and not give up after the first, unsuccessful, try.

The third requirement involves the communication problem alluded to earlier. The researcher (in a university, DOD lab, or anywhere) must, repeat must, present his product in an attractive manner and in language the user can understand. Otherwise, there will be a communications gap and a long time between data acquisition and data application. The user--let's say he is an Army human factors engineer--has his own language barrier or message set problem. He has to communicate with the designer or the field commander. He doesn't have time to learn four or five new languages. Maybe this isn't the optimal situation, but it's the way things are. If your research data is not presented in an aggressive, yet attractive fashion (like the best thing since the toothbrush) and in language he can undersantd, he will merely send your data to "File 13." I recall a review we performed at a contractor's shop some years ago. One of the investigators stated candidly that he didn't "dig" this interdisciplinary applied research. "My hangup is so and so..." The review panel unanimously recommended that either he start identifying with the real world or get off the program. He got off.

Some researchers seem to feel that once they have published their data in a "learned" journal their communication and coupling requirements have been met. Not so, as Dr. Dudek has already pointed out. If the communication process stops there it may be decades before the data ever comes to the surface in

the real world. Our human engineer who is trying to solve a project manager's problem doesn't read Perception and Psychophysics. He doesn't have time and can't speak the language. He reads, instead, "Morgan, et al." (Human Engineering Guide to Equipment Design, McGraw-Hill, 1963), or HEL design standards, or the synthesized data and recommendations of the NRC Vision Committee, or (hopefully) the proceedings of a conference on continuous operations. In short, the user reads what he can understand. And people who want their data to be used write so it can be understood and applied. This means the researcher has to be bilingual so he can, at once, communicate with his own discipline and with the user.

I am deeply involved in a communications gap problem right now. For years we acousticians have been expressing noise hazards in terms of "decibels of hearing loss." And we have been wondering, all the while, why the field commanders (for example) aren't more excited about hearing conservation. Finally we realized we weren't communicating. The field commander knows what hearing is, and he knows that his men have to be able to hear in order to understand speech or detect the presence of the enemy, but most of them never heard of "decibels of hearing loss." So now we are attempting to translate existing noise criteria into performance terminology--the user's language--so commanders can better assess noise hazards.

There is a fairly simple method for determining which THEMIS contractors are successful at selling their products (or at least trying to). Each semi-annual progress report contains a section titled: "Advisory Assistance Given." Checking reports from several contracts you will find numbers of entries ranging from zero to more than a dozen. Sometimes the assistance is given directly to DOD agencies; in other cases it represents help given to other government departments or to other DOD contractors. I would say that if the contract has been in existence for a couple of years or more, and the number of contacts per six months is less than three or four, then the contractor better check my three points--above--to see where he is falling down.

One final thought. Some people have referred to the human factors "game" as "one big travelling road show." The fact is that you have to go where the action is. I am monitoring a contract at another Texas institution, not far away from here, but over a thousand miles from where the action is. That group is regularly rendering face-to-face assistance to users in California, Massachusetts, Florida, Maryland, and Washington, DC, etc. They are going where the action is, and their work is acclaimed as some of the most significant DOD-related behavioral science work that is in progress at present. Incidentally, they have also published about 50 articles in "learned" journals, so the group is truly bilingual.

CLAY GEORGE: Look at Dr. Speck's matrix of problems. Any organization, university or not, working on continuous operations is in the interdisciplinary business and is going to have exactly the same kind of problems in organization and coordination of the effort that universities have. There is a general need to look at the points of reinforcement in the system so that people who do the maximum job, no matter what their basic background, are going to be differentially reinforced for meeting any of the goals for the organization.

ENVIRONMENTAL QUALITY CONSIDERATIONS FOR CONTINUOUS OPERATIONS

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## INTRODUCTION

For the past ten years we have been investigating the effects of noise and blast on man. The results of these experiments have been applied in the development of acoustical design criteria for new Army equipment. During the past year we have been reviewing the state-of-the-art with respect to noise criteria, to determine where we need to go to be able to meet the requirements of the future Army with respect to continuous operations. One thing we need is exposure limits for long-term noise exposure. However, there are other air-borne pollutants besides noise. In this brief report I would like also to note the current status of design criteria for fumes and vapors and some of the improvements needed in this area as well.

## NOISE CRITERIA

Assessment of the potential hazards of noise exposure in military environments is made by means of "damage-risk" criteria (DRC). The best available DRC for steady-state and intermittent noise are those developed by Working Group 46 of the NAS-NRC Committee on Hearing, Bioacoustics and Biomechanics (the "CHABA" committee) (4).

Figure 1 illustrates one damage-risk contour from the CHABA DRC for steady-state noise. This one is for a single daily exposure to bands of noise. The left-hand ordinate is octave-band sound-pressure level (SPL) in dB re 20 $\mu N/m^2$, and the right-hand ordinate is 1/3-octave-band SPL. The abscissa is band center frequency in Hz. The nine contours show the permissible noise levels for various exposure times from 1-1/2 minutes to 8 hours per day. In practice, the SPLs measured in a particular environment would be plotted on the graph and the highest penetration would define the maximum exposure time permitted by the DRC. If exposed personnel are wearing hearing protection,

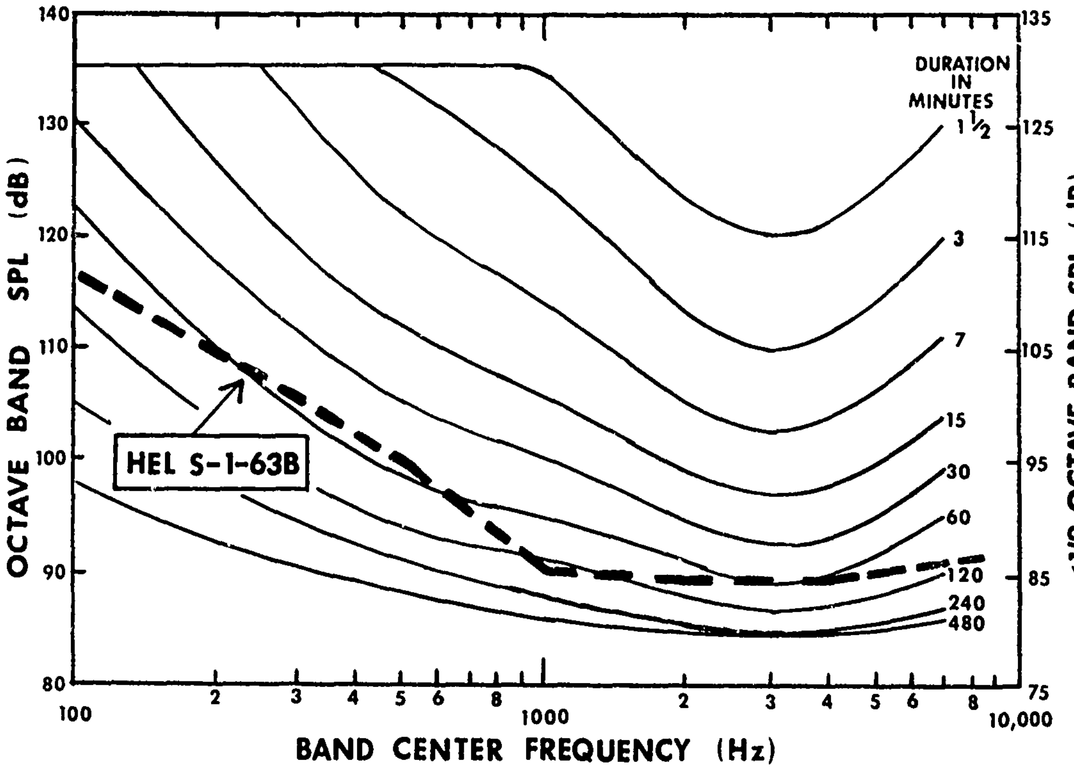


Fig. 1. CHABA DAMAGE-RISK CONTOURS FOR EXPOSURE TO BANDS OF NOISE. DASHED CURVE IS CURRENT AMC EQUIPMENT DESIGN STANDARD.

the environmental noise spectrum can be reduced by the attenuation of the particular device being worn and the permissible exposure time for protected personnel can thereby be determined.

Another set of contours in the DRC expresses these same relationships in such a way that if you knew what exposure time was required to perform a particular job (up to 8 hours) you could determine the permissible octave- or 1/3-octave-band SPL. Also, the DRC provides other contours for evaluating pure tone and intermittent noise exposures.

The risk of hearing damage specified by the CHABA DRC is as follows: maximum permissible temporary threshold shift (TTS) measured two minutes after exposure ($TTS_2$) is 10 dB at or below 1 kHz, 15 dB at 2 kHz, and 20 dB at or above 3 kHz in 50 percent of exposed ears. These amounts of $TTS_2$ are designed primarily to preserve man's ability to communicate by speech, since greater emphasis is placed on limiting TTS in the lower, speech frequencies than in

the upper frequencies of hearing.

The design standard for Army materiel is contained in HEL Standard S-1-63B (6). These maximum noise level limits are incorporated into MIL-STD-1472A (10). Figure 1 also shows the noise limits of HEL S-1-63B plotted against the CHABA steady noise DRC. The design standard's limits fall between the 60 and 120 minute exposure contours. In deriving these limits a number of points were considered, including the following:

a. In many cases, Army materiel is not operated for long periods of time (according to present tactical doctrine). Certainly, it is rare to find situations in which personnel are exposed to noise for eight hours a day, five days per week.

b. Hearing protection will be worn by personnel in many situations, or communications gear will be used which provides protection against noise.

c. Noise reduction is expensive and often results in loss of operational effectiveness of materiel. Thus, a realistic tradeoff between desireable and achieveable noise limits is often indicated.

The design standard is an official inclosure to Army procurement actions, and is also incorporated into the Test and Evaluation Command's acceptance criteria (3). Materiel not meeting the S-1-63B limits must be labelled in accordance with Army Regulation 385-30 (9) as follows:

CAUTION

HIGH INTENSITY NOISE

HEARING PROTECTION REQUIRED.

Regarding noise criteria for continuous operations, for steady-state noise we presently have no systematic criteria at all for exposures longer than eight hours. (This may be a problem for industry as well as the Army, since industry is experimenting with a 10-hour work day, and the Walsh-Healy Public Contracts Act (11) does not provide for exposures longer than eight hours per day.)

There has been little investigation of the effects of long exposures. The few data which are available are contradictory, and suggest that much needs to be done in this area. Figure 2 shows some results from a recent study by Mills, et al. (12). A single subject was exposed to an octave-band of noise centered at 500 Hz. Hearing thresholds were monitored at 750 Hz. Two SPLs were used: 81.5 and 92.5 dB. Both curves in Fig. 2 indicate that an asymptote in TTS growth was reached after about 12 hours of exposure.

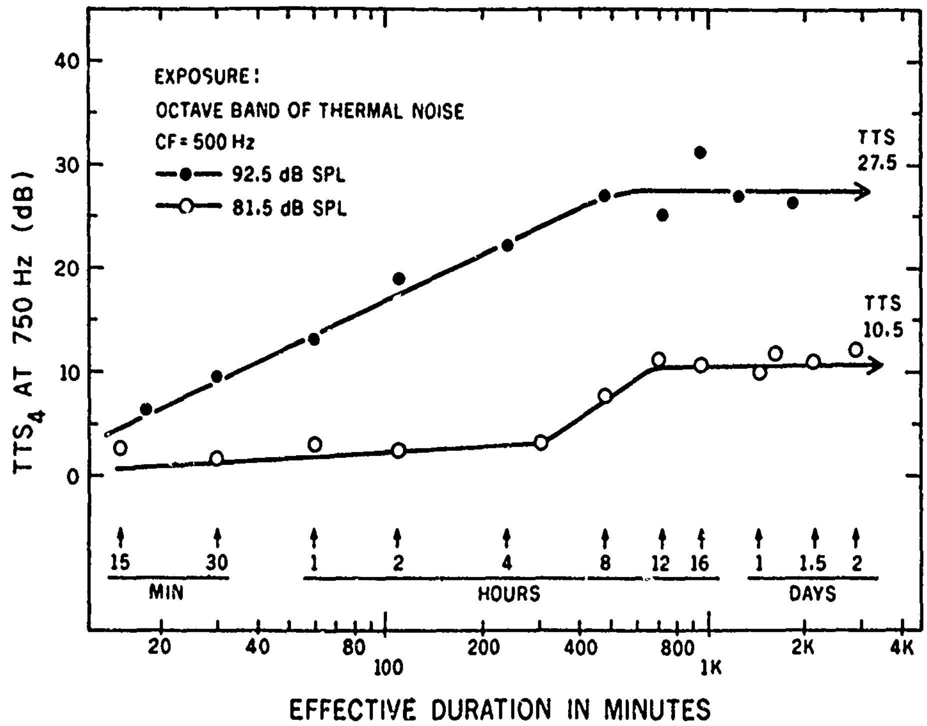


Fig. 2. GROWTH OF TEMPORARY THRESHOLD SHIFT FOR A LONG EXPOSURE AS REPORTED BY MILLS, ET AL. (12).

Figure 3 shows some results from an experiment conducted by Yuganov, et al. (15) in the Russian astronautics program. Here, several astronauts were exposed to broad-band noise at 75 dB SPL for 30 days continuously (720 hours). The figure shows the reported "average TTS" values. These data suggest that for a broad-band noise exposure TTS continues to grow linearly in the logarithm of time over the entire course of the exposure. The contradictory nature of the data reported by Mills, et al., vs those of Yuganov, et al., indicate that further research is needed on the effects of long-term noise exposure.

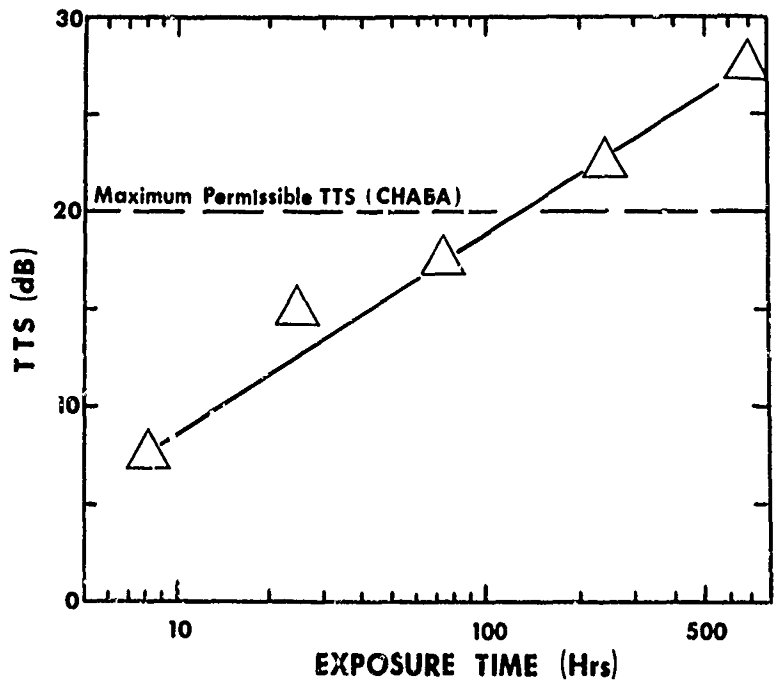


Fig. 3. GROWTH OF TEMPORARY THRESHOLD SHIFT FOR A LONG EXPOSURE AS REPORTED BY YUGANOV, ET AL. (15).

Another aspect of long-term noise exposure requires evaluation: the characteristics of recovery from TTS induced by long exposures. Both Mills and Yuganov indicated that recovery took much longer than for the same amount of TTS resulting from shorter exposures. Figure 4 is from Mills' paper and shows the recovery functions for his one subject. The dashed lines has been added to show the TTS recovery functions implicit in the CHABA DRC. TTS induced by the lower SPL should have, according to the CHABA DRC, recovered within about 45 minutes; it took four days. For the upper curve, recovery should have been complete within about eight hours; it took six days. This matter requires investigation because one of the most critical questions in the continuous operations area is: "How long does it take the soldier to recover from the effects of long-term performance, including long-term exposure to various environmental pollutants?"

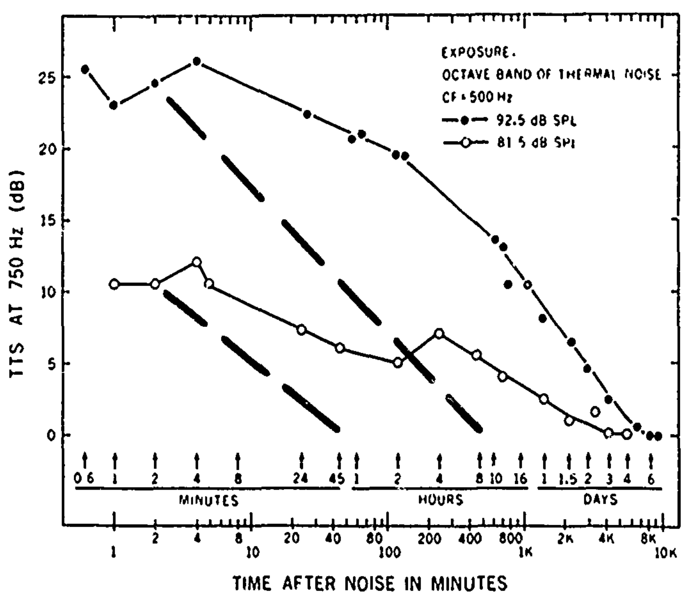


Fig. 4. RECOVERY OF TEMPORARY THRESHOLD SHIFT INDUCED BY LONG-TERM NOISE EXPOSURE, AS REPORTED BY MILLS, ET AL. (12). DASHED LINES HAVE BEEN ADDED TO SHOW RECOVERY FUNCTIONS IMPLICIT IN THE CHABA DAMAGE-RISK CRITERION (4).

We, at the Human Engineering Laboratories, are presently considering these problems and defining an appropriate research program designed to provide the answers. Several aspects will be considered. One goal is the development of "CHABA-DRC-like" exposure contours for exposures longer than eight hours. Another goal is determining the effects of the current eight-hour criterion SPLs on hearing during longer exposures. Then, including the recovery aspect, it may be necessary to establish exposure limits for TTS that will recover within the 16 hours currently implicit in the CHABA DRC.

## EXPOSURE LIMITS FOR FUMES AND VAPORS

In thinking about the need for long-term noise exposure criteria it occurred to me that perhaps we need similar criteria for long-term exposures to other atmospheric pollutants such as fumes, vapors, etc. Material which was readily available was surveyed and this brief discussion is the result.

Paragraph 5.13.7.3 of MIL-STD-1472A (10) provides typical design guidance and reads as follows: "Personnel shall not be exposed to toxic substances in excess of the threshold limit values contained in the American Conference of Government Industrial Hygienists -- Threshold Limit Values" (p. 168). Similar instructions may be found in current HEL standards for various types of military equipment (5, 7, 8, 14).

What is a "threshold limit value?" The preface to the 1970 Threshold Limit Values adopted by the ACGIH (1) reads as follows:

> Threshold limit values refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect.... (p. 1)
>
> Threshold limit values refer to time-weighted concentrations for a 7 or 8-hour workday and a 40-hour workweek. They should be used as guides in the control of health hazards and should not be used as fine lines between safe and dangerous concentrations. (Exceptions are ... those substances with a "C" or Ceiling Value....) (p. 1)

> ... They are not intended for use ... in estimating the toxic potential of continuous uninterrupted exposures.... (p. 2)

Thus the Threshold Limit Values are not appropriate for evaluating working environments under continuous operations conditions, and other guidance must be sought for this purpose.

The problem of long-term exposure to fumes and vapors has been considered by the NRC Committee on Toxicology which published, in 1968, "A Compendium of Recommendations of Safe Concentrations of Atmospheric Contaminants" (2). This document's introduction reads, in part, as follows:

> These values have been recommended by the National Research Council Committee on Toxicology for specific circumstances involving long periods of continuous exposure in confined spaces such as nuclear submarines and spacecraft. They are ... atmospheric concentrations which the Committee believes will produce no toxic effect or discomfort under the intended circumstances of exposure. Each contaminant has been considered separately without regard to possible interactions with other contaminants present simultaneously..... (p. 2)
>
> Ninety-Day Exposures. These recommended levels are average values which ... may be applied to any period of continuous exposure up to ninety days. (p. 2)

In addition to the NRC recommendations, the Naval Submarine Medical Center has published its own set of recommendations and exposure limits for long-term exposure (13).

Table 1 compares the eight-hour TLV (1), 90-day NRC (2) and 90-day USN (13) exposure limits for a selected group of toxic air-borne vapors and fumes. The five compounds indicated by the superscript "d" are known constituents of the exhaust from internal-combustion engines, and thus would definitely be of concern to the Army. In addition, the three Freon compounds are of concern in any environment where air-conditioning or refrigeration equipment is used. The compounds preceeded by an asterisk indicate those for which the 90-day exposure limit is less than the eight-hour limit which,

Table 1

RECOMMENDATIONS FOR ATMOSPHERIC CONTAMINANTS

(ppm by volume unless otherwise noted)

| Contaminant | 8-hr TLV[a] | 90-day Exposure[b] | 90-day Exposure[c] |
|---|---|---|---|
| *Acetone | 1000 | 300 | --- |
| Ammonia[d] | 25 | 25 | 25 |
| *Arsine | 0.05 | 0.01 | 0.01 |
| *Benzene | 80 $mg/m^3$ | 3 $mg/m^3$ | --- |
| Carbon Dioxide[d] | 5000 | 5000 | 6-10,000 |
| *Carbon Monoxide[d] | 50 | 25 | 25 |
| *Chlorine | 1 C | 0.1 | 0.5 |
| *Ethanol | 1000 | 100 | --- |
| *Freon 11 | 1000 | 1000 | 500 |
| *Freon 12 | 1000 | 1000 | 500 |
| Freon 114 | 1000 | 1000 | --- |
| *Hydrogen Chloride | 5 C | 1 | 0.1 |
| *Hydrogen Fluoride | 3 | 0.1 | 0.1 |
| *Isopropanol | 400 | 50 | --- |
| *Mercury | 0.05 $mg/m^3$ | 0.01 $mg/m^3$ | --- |
| *Methanol | 200 | 10 | 3 |
| *Methyl Chloroform | 350 | 200 | --- |
| *Nitrogen Dioxide[d] | 5 C | 0.5 | 0.5 |
| *Ozone | 0.1 | 0.02 | 0.05 |
| *Phosgene | 0.1 | 0.05 | 0.05 |
| *Stibine | 0.1 | 0.01 | 0.05 |
| *Sulfur Dioxide[d] | 5 | 1 | --- |
| *Toluene | 750 $mg/m^3$ | 10 $mg/m^3$ | 20 |
| *Triaryl Phosphates | 5 $mg/m^3$ | 1 $mg/m^3$ | --- |
| *Xylene | 435 $mg/m^3$ | 10 $mg/m^3$ | 3 |

[a] American Conference of Governmental Industrial Hygienists, 1970 (1).

[b] NRC Committee on Toxicology, 1968 (2).

[c] USN Submarine Medical Center, 1965 (13).

[d] Known constituents of exhaust from internal combustion engines.

* Contaminants for which 90-day exposure limit is less than 8-hr TLV.

in this case, includes all but three of the listed compounds. It may be worth noting, in addition, that for three compounds to which the ACGIH has assigned a Ceiling Value, which means that they are not to be exceeded under any circumstances, the 90-day exposure limit is significantly lower than the Ceiling Value.

Several types of data and/or recommendations may be needed in this area to evaluate continuous operations problems:

a. Long-term exposure criteria for, say, five days.

b. Estimates of the effect of eight-hour-limit exposure levels experienced for periods longer than eight hours.

c. An Army document which treats the problem of long-term exposure.

An Army agency specializing in toxicity problems, such as the US Army Environmental Health Agency, should be requested to develop the needed recommendations and define any new research which may be required for long-term exposure to toxic fumes and vapors.

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## DISCUSSION SESSION

## DAVID HODGE

CLAY GEORGE: Are people looking at the effect of noise of sudden onset? This is not exactly the intermittent noise situation, but the unpredictable occurrence in time and type and amount of noise and its accumulative effect on circadian rhythm.

DAVID HODGE: Are you referring to things like "startle?" There is work like this going on, particularly the startling effect of things like the sonic boom. In our own laboratories there is work being conducted on the effect of noise level on performance of tasks like aiming, etc. Yes, there is considerable interest in this particular problem.

BEN B. MORGAN, JR.: This brings to mind, since I am interested basically in performance, the synergistic effects of environmental factors on performance: the problem of the interaction of stressors in continuous operations. For example, you might have your noise or the toxic gases interacting with the stress imposed by the continuous work. This is something that will have to be considered somewhere down the road.

DAVID HODGE: While I was in Miskolc, Hungary, a couple of weeks ago, I talked with a West German scientist who ran an experiment with all the subjects being exposed to the same noise level. One group was a control. Another group got noise as a reward; the third group got noise as a punishment. He reported that he found significant differences in the amount of temporary hearing loss, depending on whether the noise was a reward or punishment. There is certainly a lot of interaction going on.

# WORK-REST SCHEDULES UNDER PROLONGED VIBRATION WITH IMPLICATIONS TO MILITARY OPERATIONS[1]

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## INTRODUCTION

Vibrational environments have always been experienced in military operations, e.g., by tank, aircraft and naval craft crews. Thus, interest by the military in the results of research concerned with vibrational environments is very understandable.

Understanding the effects of vibrational environment is ever increasing. Human tolerance limits and subjective reaction to vibration have been well documented (24), (19), (25), (16), (2), (17), (31), (29) and (5). Attempts are being made to establish vibration standards and exposure limits (23). Harmful effects of vibration have been studied (6) and (14). Mechanical simulation of human response to vibration has been investigated by many researchers in Europe and America, e.g., (7), (8), (10) and (34). The effects of vibration on human performance has also received considerable attention, e.g., effects on tracking efficiency (32), (35), (1), (15), (21), (33), (4), (18) and (20),

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on visual accuity and reaction time (9), (22), (30), (35), (36) and (37), and on motor performance and body configuration (12), (3) and (26).

The subjects of the research discussed here relates to the effects of prolonged vibrations on performance and recovery, and the best combinations of work-rest schedules for the maintenance of highest level individual and crew performance.

## SINGLE STATION CREW STUDY: ONE HOUR MISSION STUDY

A study conducted by Khalil and Ayoub (27) and (28), investigated the effects of work-rest schedules upon an individual's performance of a vertical compensatory tracking task performed under normal and vibratory environments. Four work-rest schedules; viz. 30/30 minutes, 15/15 minutes, 10/10 minutes and 5/5 minutes; were used within an hour's duration. Both work and rest periods were experienced under the same environmental condition. A recovery period of 15 minutes was also studied. Seven male subjects were required to perform a vertical compensatory tracking task utilizing a CRT display. The deviation of the controlled element from the target represented the tracking error which was integrated over time (the first 45 seconds of each minute of performance) by means of an analog computer. The vibratory environment was vertical sinusoidal with frequency of 5 Hz, amplitude of 0.16 inches (DA), and acceleration intensity level of 0.20g.

Some significant conclusions drawn from this study were:

1. A vibratory environment causes significant decrement in vertical tracking ability. Absolute tracking error score increased by as much as 43 percent under vertical vibration.

2. Complete recovery from vibration did not occur during the allowed period (15 minutes) for recovery.

3. The work-rest schedules having the longer work-rest phases (30/30 minutes W/R) showed <u>less</u> decrement in

performance as measured by average error scores resulting from vibration than those having shorter work phases (see Figure 1).

## SINGLE STATION CREW STUDY: TWO HOUR MISSION STUDY

A continuation study was conducted by Dudek, Ayoub and El-Nawawi (11) to investigate the effects of longer work-rest schedules on an individual's vertical compensatory tracking performance. This investigation was undertaken because of an observation made by Khalil and Ayoub that "there may be an optimum work-rest schedule which would result in minimum decrement when utilized under a certain level of vibration." The study was designed to investigate the hypothesis of the existence of an optimal work-rest schedule for a vertical compensatory tracking task performed under normal and vibration environments. The task, experimental procedure and environments were those reported by Khalil and Ayoub. However, a longer duration experiment (2 hours) was conducted followed by a 30 minute period of recovery. Three work-rest schedules were utilized, viz. 30/30 minutes, 40/40 minutes and 60/60 minutes. Five male students, all of whom participated in the previous study, served as subjects in this experiment.

At this point, some discussion of the results obtained under the longer work-rest schedules is pertinent. Figure 2 is a plot of the interaction effects on performance of the 30/30 and 60/60 minute work-rest schedules by period by environment. In order to reduce confusion in this figure, the middle work-rest schedule (40/40 minute) data was not plotted. It is clear that under normal environment, the error score increases; that is, the 30/30 minutes work-rest schedule showed the lowest error score and it increased as the work-rest schedule changed to 40/40 and 60/60 minutes. This result supports the findings of Khalil and Ayoub. However, it is interesting to note that the effect of the work-rest schedule under the vibratory environment was different. As the work-rest schedule changed from the 30/30 to the 60/60 minutes,

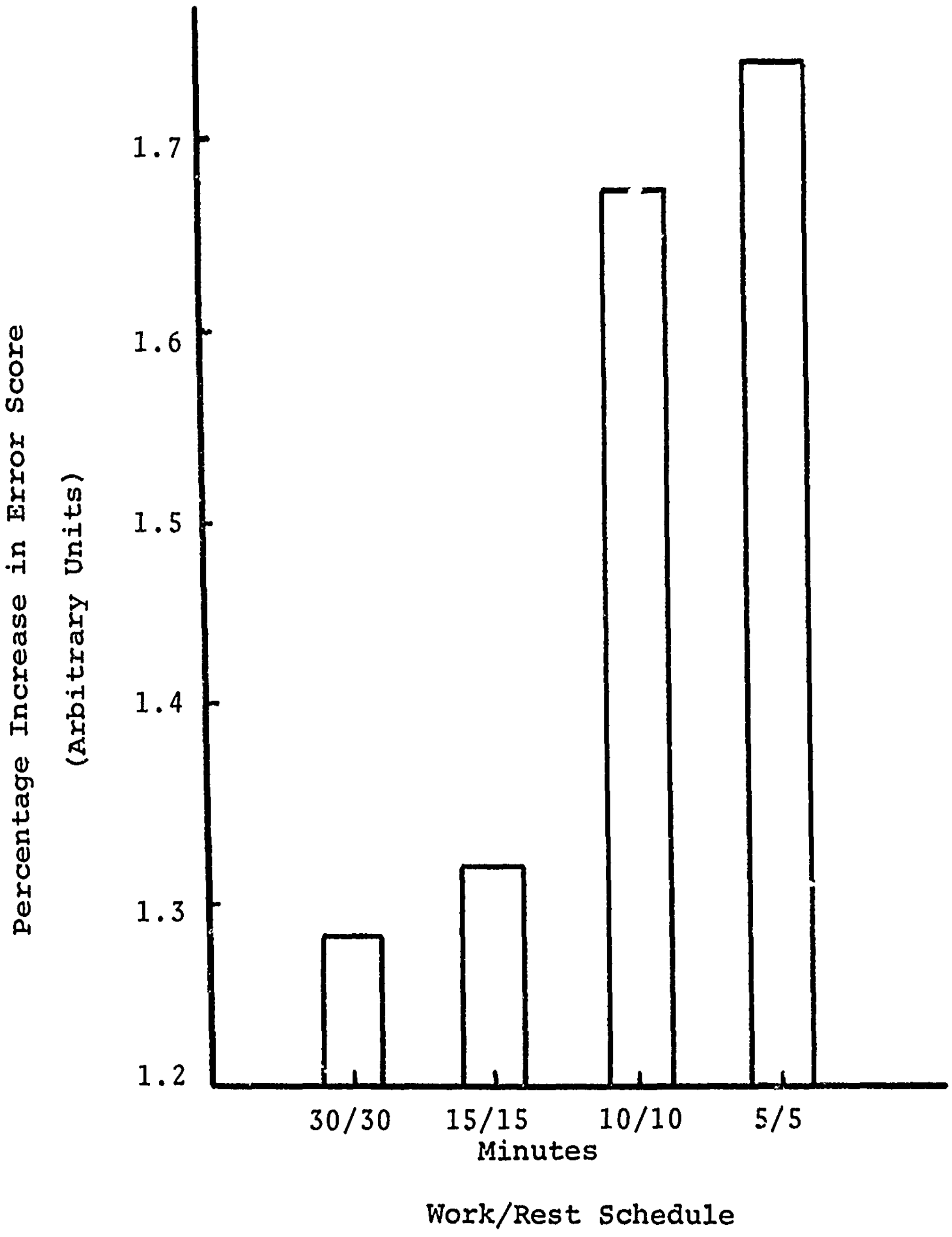


Figure 1. Plot of Means for Percentage Increase in Error Score Versus Work/Rest Schedule (Vibration).

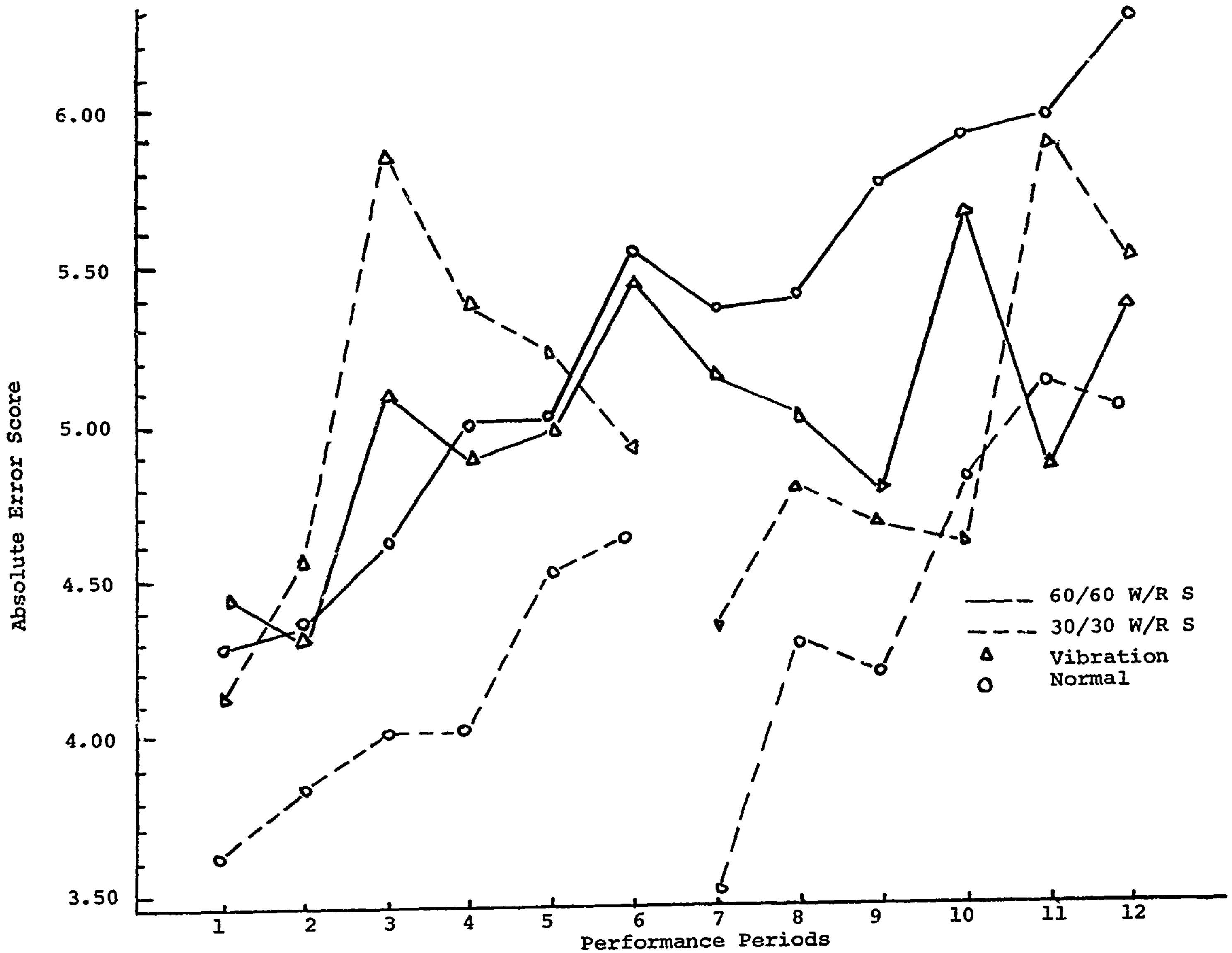


Figure 2. Error Score for 30/30 and 60/60 W/R Schedule X Period X Environment

there was a very small difference in the error score. It is evident from this result that under the normal environment, especially under the 40/40 and 60/60 minute schedules, the task "boredom component" considerably influenced the operator's performance; whereas, under the vibratory environment the boredom component's effect was reduced, due to the stimulus received by the operator from the environment. This resulted in an improvement of performance under the vibratory environment over that under normal environment for the 60/60 minute work-rest schedule. To compare the sensitivity of the work-rest schedule under the environments, the difference in error score for the normal and vibratory environments under each work-rest schedule was used as a measure. The results of this test indicate that although performance under the 30/30 minute work-rest schedule was generally better, it was most susceptible to the detrimental effect from vibration.

Based upon the results of the two studies conducted, the pertinent conclusions are:

1. In general the 30/30 minute work-rest schedule appears to be best under all conditions used in these studies, i.e., a compensatory tracking task performed under both normal and vibration environments (the latter being 5 Hz and 0.2g acceleration magnitude) with both work and rest experienced under the respective environment.

2. A best work-rest schedule is dependent upon several factors, such as task components, environment, etc., and/or their interaction.

   This is evidenced in Figure 3 where it appears that as the work-rest schedule increases in length (from 5/5 minutes to 60/60 minutes) the tracking performance under normal environment does not seem to be significantly affected up to a 30/30 minute work-rest schedule, after which it begins to deteriorate with largest decrement occuring at a 60/60 minute schedule. On the

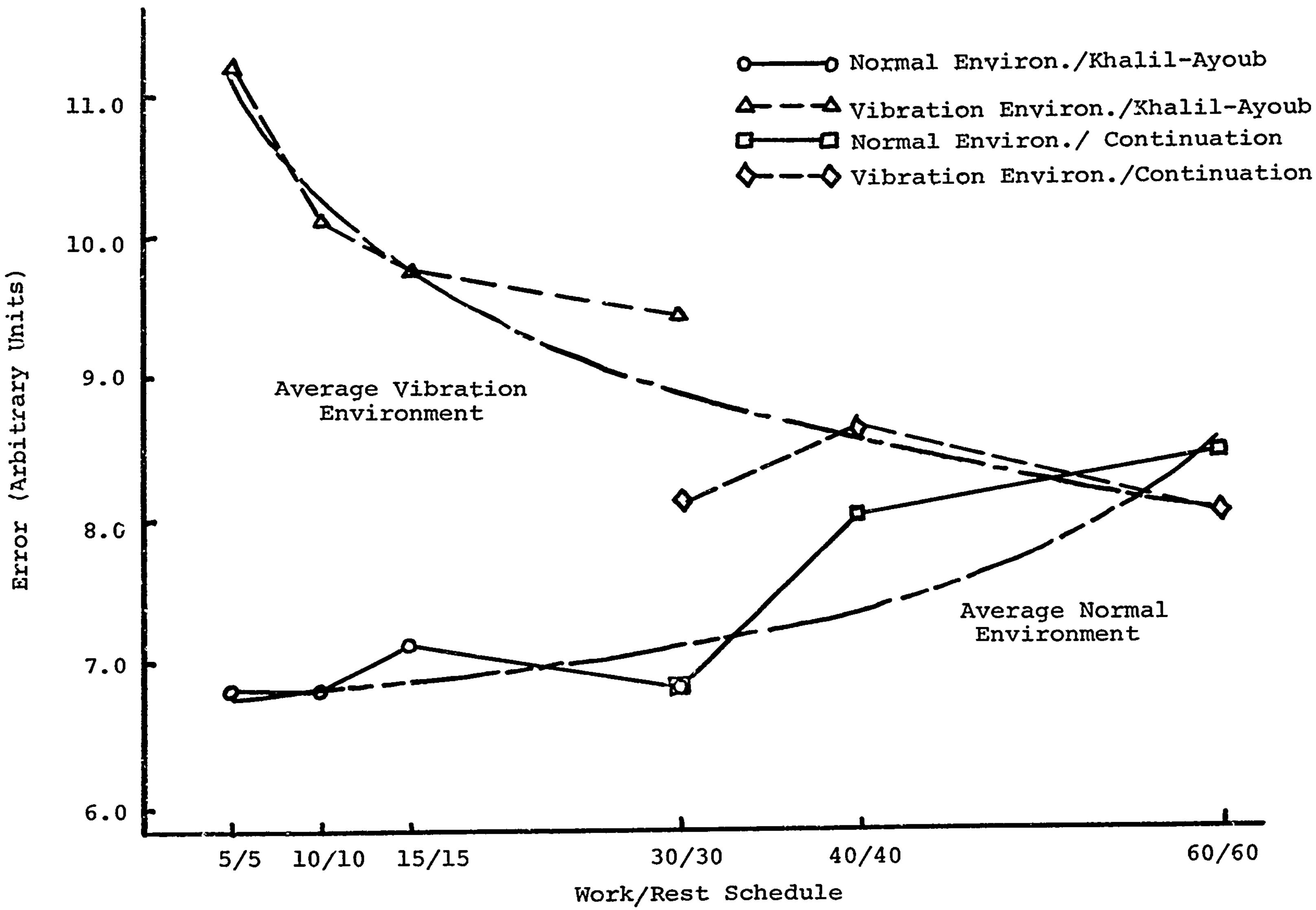


Figure 3. General Effect of Work/Rest Schedule and Environment On Error Score of Tracking Task

other hand, under a vibration environment the tracking performance appears to improve almost exponentially as the work-rest schedule increases reaching a value at the 60/60 minute schedule below that achieved under a normal environment.

3. Task boredom and/or fatigue seems to be a most important component which should receive attention. On longer mission periods, it appears to be the major disruptive factor.

MULTI-STATION CREW STUDY: FOUR HOUR MISSION STUDY

At this stage it was of interest to obtain some understanding of the effect of a vibratory environment upon the performance of a group of individuals (crews). Therefore, El-Nawawi (13) studied the effects on performance of different crew sizes ($n_1$, $n_2$, ...) operating (m) stations of a multi-station work system ($n \geq m$) of both normal and vibration environments. The purpose of the research was to study man's performance and recovery characteristics when performing a one-dimensional vertical compensatory tracking task while working in accordance with different work schedules, determined by the crew size and multi-station system, and subjected to whole body, low frequency sinusoidal vertical vibration. The task and environment variables and the performance measure (though for total crew performance) were the same as those used in the previous experiments. However, the resting portion at the work cycle was experienced under normal (no-vibration) environment, mission duration was 4 hours and a recovery period of 20 minutes was used. A simulated 4 station work system was investigated with assignment of subjects to simulate 8, 6, and 5-man crew operation with two work cycles (60 minute and 30 minute) used in the crew schedules. Thus, three work/rest ratios were employed, viz. 1/1, 2/1 and 4/1, since the assignment of an 8-man crew to the system established a 60/60 and a 30/30 minute work-rest schedule while the assignment of a 4 man-crew to the system established a 60/15 and a 30/7.5 minute

work-rest schedule. Two typical work schedules, with a 30 minute work cycle for the 8-man and 4-man crews, are shown in Figures 4 and 5, respectively. In order to keep motivation of all crew members at a high level, they were paid for all hours of experimentation and a special bonus was awarded to the two subjects with best overall performance.

Since this study was concerned with total crew operation of a multi-station work system, only inferences can be made regarding work schedules and work-rest ratios best suited for operation on the system. It is difficult to draw direct conclusions concerning work schedules and work-rest ratios utilizing the criterion of performance of different size crews, for once a crew size and work cycle are designated for operation of the system a specific work-rest ratio and work schedule are prescribed.

Pertinent conclusions concerning crew operations of multi-stations are the following:

1. Tracking error scores increased with the decrease in crew size operating the work system. The best performance was yielded when crew members were scheduled to work in accordance with the 1/1 work-rest ratio (8-man crew operating a 4-station work system). The 6- and 5-man crews, whose members were scheduled in the 2/1 and 4/1 work-rest ratios respectively, resulted in higher tracking error scores (see Figure 6).

2. Tracking error scores increased up to 21% under vertical vibration as compared to 43% in the Khalil-Ayoub study. (Recall that rest in this study was experienced under normal environment rather than under vibration environment.)

3. The vibration effect on tracking decrement remained the same during the first and second 2-hours of the mission with wider dispersion in the latter 2-hours as well as indication of the affect of fatigue and/or boredom. (see Figure 7)

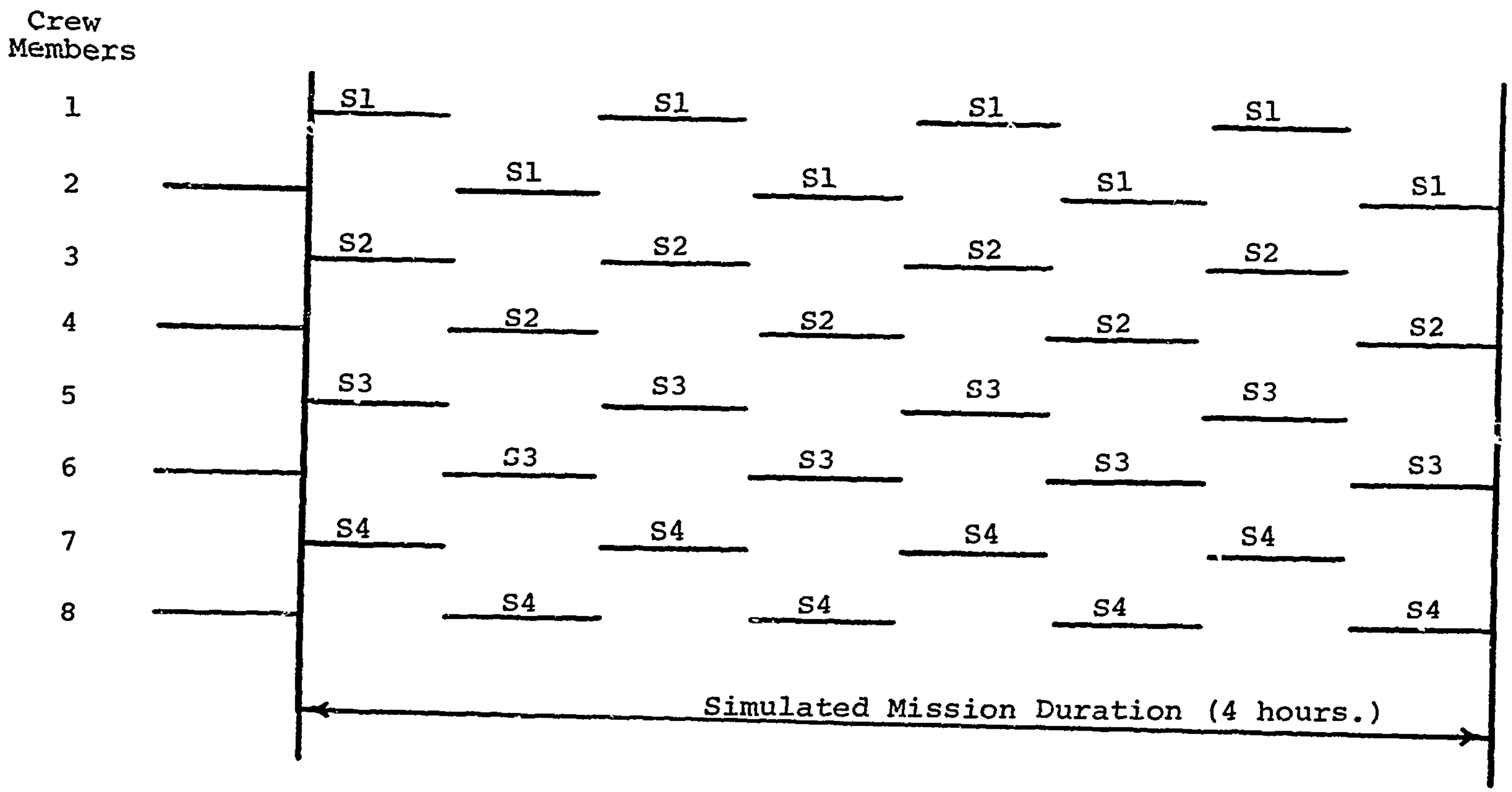


Figure 4. Scheduling chart Showing the Eight-Man Crew Members as Assigned to Operate the 4-station Work System, Length of Work Cycle Being 30 Mirutes

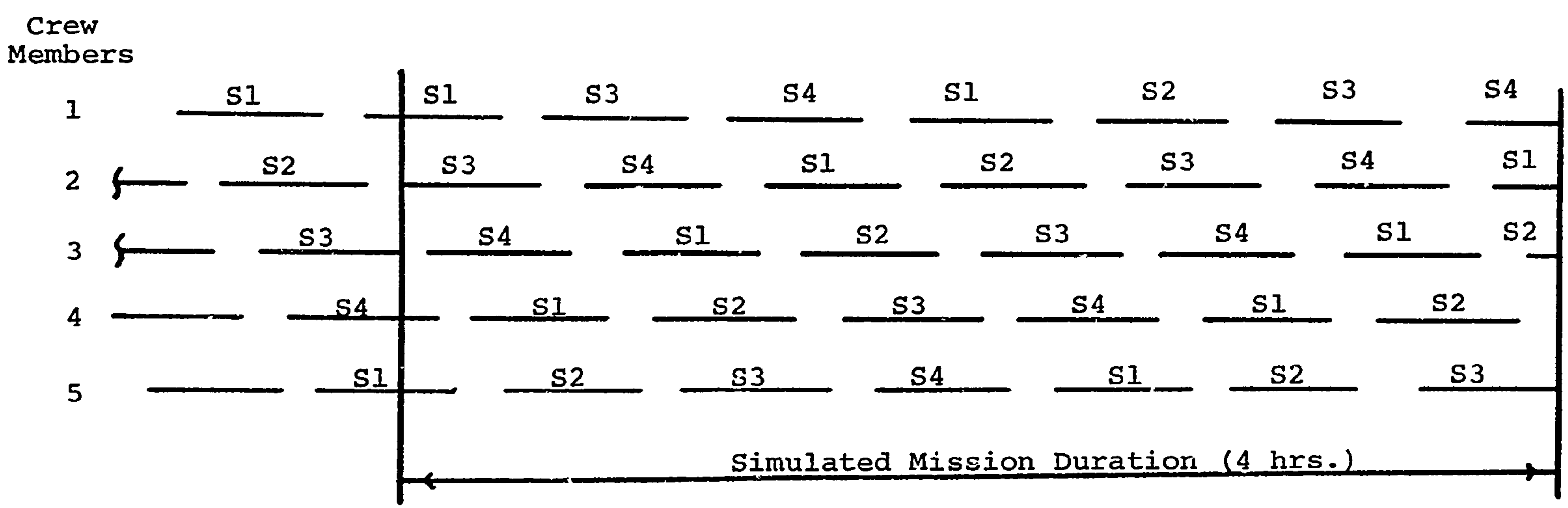


Figure 5. Scheduling Chart Showing the Five-Man Crew Members as Assigned to Operate the 4-station Work System, Length of Work Cycle Being 30 Minutes

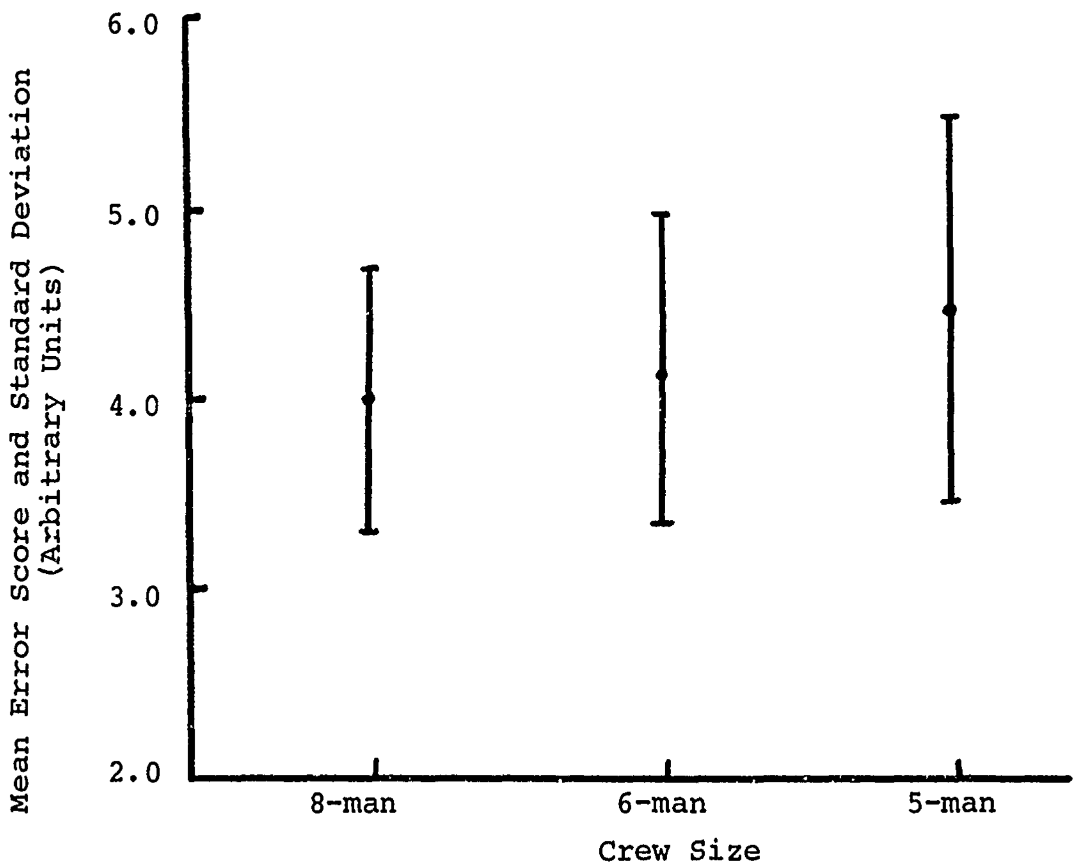


Figure 6. Plot of Means and Standard Deviations of Tracking Error Score Versus Crew Size During the Entire 4-hour Mission

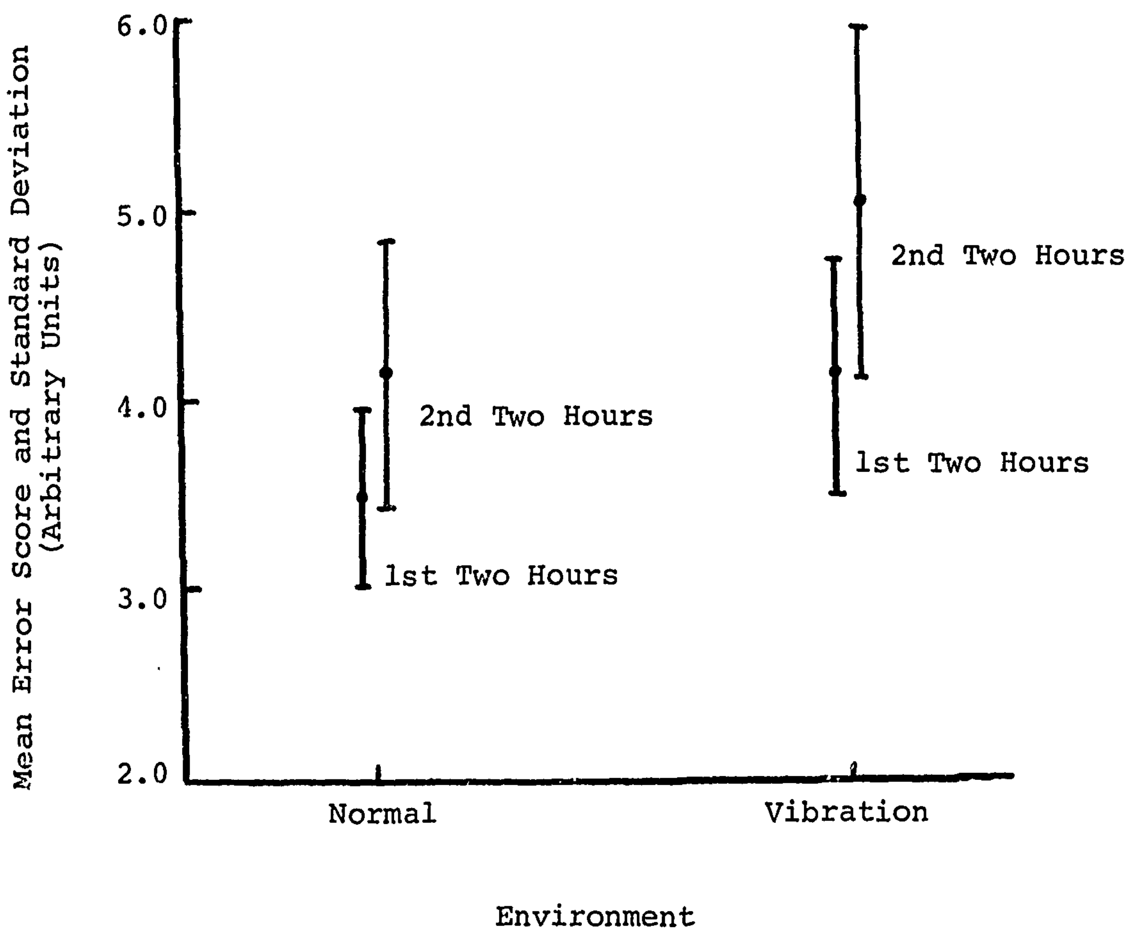


Figure 7. Plot of Means and Standard Deviations of Tracking Error Score Versus Environment During the First and Second Two Hours of Mission

4. In general the 30 minute work cycle schedules yielded lower tracking error scores than those obtained under the 60 minute work cycle schedules which is interesting for the multi-station crew results reflect the results concerning individual's performance on single station indicated in the first two studies. However, the advantage of performance for the 30 minute work cycle schedules was greatly affected in the long-duration (last 2 hours) missions, especially under the vibration environment, which can be attributed to the smaller rest sessions provided in the work schedules.

## SUMMARY

The research discussed here focused attention upon investigation of work schedules for single and multi-station crews performing tasks, viz. a compensatory tracking task, when subjected to a vibrational environment. Indications of beneficial work schedules and work-rest ratios are provided.

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## DISCUSSION SESSION

## R. A. DUDEK

BEN B. MORGAN, JR.: Was there any difference whether or not subjects rested under normal or vibration conditions?

R. A. DUDEK: Well, the only thing we have there is the indication that the decrement for the latter study in which subjects rested under normal vibration increased only up to 21% while in the other two studies we got decrements as high as 43%. Therefore, there was a difference because the subjects recovered partially in each rest period. Subjects are almost totally recovered after a 25 minute period. The 15 minute recovery period that was used in the Khalil-Ayoub studies wasn't quite long enough but 30 minute recovery period used in the second study was longer than required. The 20 minute period used in this last study wasn't quite long enough even though resting was under normal environment but a working period of four hours was used. So resting environment and period really does make a difference. It is reasonable to consider conditions under which operators rest under normal conditions. Consider a mission to keep four helicopters in the air constantly, you could use five, six or eight crews and give them different amounts of rest on the ground, by rotating them through the work session. Or if you want four vehicles running simultaneously, and want them operational all the time. If you start with five crews, with one always resting, they could do their rest under normal conditions rather than under vibratory conditions.

DAVID HODGE: How much of a bonus were these people promised for a good performance.

R. A. DUDEK: I think, was it $50 and $40 or $50 and $30. And to college students, who were the subjects, this was meaningful. We think that it was meaningful based on the comments made to us by the subjects.

# SELF DETERMINED WORK/REST CYCLES IN THE HEAT[1]

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## INTRODUCTION

This paper addresses itself to two problems: first, the selection of a rest schedule which will optimize performance on a monitoring type task, and second, the influence of working in a hot environment on both performance and on selection of a work/rest schedule.

Despite modern technological advances in climate control and air conditioning a large segment of industrial and military work is still performed in ambient temperature conditions that exceed desirable comfort ranges. Considerable research has been reported concerning monitoring performance under conditions of thermal loading (e.g., (9), (12), (3), (1), (16), and (13). Results concerning specific performance decrement has sometimes been contradictory but in general hot work conditions tend to cause poorer monitoring scores.

The optimal assignment of working man into a work/rest schedule has also been a concern of many investigators. Chiles, Alluisi and Adams (4) report an 8 year program of research into work/rest schedules during confinement. Colquhoun, Blake and Edwards (6), as well as Wilkerson and Edwards (15), and Hartman and Cantrell (8) have similarily investigated work/rest schedules for various work shift periods. These investigators have been

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[1]This research was supported by THEMIS Contract Number DAAD05-69-C-0102, between the U.S. Department of Defense and Texas Tech University.

primarily concerned with work sessions of from 2 to 16 hours per 24 hour day. Others have evaluated work/rest over short periods. Bergum and Lehr (2) observed that 30/10 minute work/rest sessions yielded better performance than continuous 90 minute sessions. Similarily, Mackworth (10) utilized a vigilance task to demonstrate the performance improvement of two crews working one hour each as opposed to one crew working a two hour watch. Colquhoun (5) found performance during one hour checking tasks to be enhanced by the addition of a 5 minute rest period after the first 30 minutes.

This study is an attempt to evaluate characteristics of a work/rest schedule when performing a monitoring task with and without an ambient heat load. The work schedules were self-determined, that is, based on the operator's own assessment of when he needed to be relieved. A similar approach is reported by Douglas (7) who compared a self-determined schedule on an inspection task against fixed schedules of 3/2 and 13/2 minutes (work/rest). He found that gross speed on inspection was slower for the 3/2 schedule than for the others, but that net speed was not affected.

## PURPOSE

The major objectives of this study were:

1. to determine whether or not the monitoring team would develop a self determined work/rest cycle which would optimize monitoring performance over an extended period of time
2. to assess the work/rest cycle selected and to analyze the process by which team members make such a selection
3. to determine whether or not the work/rest cycle was a function of the environmental temperature in which the task was performed

It was hypothesized that if an operator was allowed to determine his own work/rest cycle, then his performance should be better

than would result from an imposed or pre-specified work/rest cycle. It was felt that this procedure of allowing subjects to select their own work/rest cycles would be a more efficient method of determining optimal work/rest periods than that of testing all possible combinations of work/rest schedules.

## EXPERIMENTAL VARIABLES

Independent variables. Three levels of ambient room temperature were utilized for this study; comfortable (74°FET), warm (82°FET), and hot (90°FET). These represent dry bulb/wet bulb temperatures of 80/67°F, 92/76°F and 102/86°F, respectively, a relative humidity of 50% and an air velocity of 80fpm.

Experimental session also served as an independent variable for this study. Each subject performed the experimental task during three successive sessions. Analysis of session effects provided information concerning learning or adjustment to schedule.

Each experimental work session consisted of one or more self determined work periods for each of the subjects on duty. It was possible to compare the first work period and the last work period for each session as a means of assessing the performance level during early and late stages of the three hour work session.

Twelve teams of two members each were utilized in this study. These subjects were male college age students in good physical health.

Dependent variables. A primary variable of interest was the time on duty selected by each individual subject team member. This was measured in terms of total time duration between starting the watch period and requesting relief from the watch.

Performance was measured in terms of signals detected while on monitoring duty. At the presentation of a signal the subject responded by pressing the hand held push button. This response was known as a "detection." In addition to a simple detection, each signal had a magnitude of either large (3/4 inch) or small

(1/4 inch) deflection. Correct identification of the signal magnitude in addition to detection of the signal result in a "correct response" measure of performance.

Controlled variables. Some experimental conditions and variables were held constant throughout the investigation in order to minimize any confounding influence. All experimental sessions were conducted at the same time of the day. The subjects were not acclimatized. A white noise of 85 decibels was played during each session in order to mask any occasional noises of the chamber or of the other subject. Motivation and knowledge of the task were standardized by written and tape recorded instructions which were presented to the subjects prior to their first work session.

## EXPERIMENTAL EQUIPMENT

An environmentally controlled chamber was utilized to control the temperature, humidity and air flow for this study. Two separate monitoring stations were constructed in the chamber so that subjects were isolated visually from one another. Each work station consisted of a chair and table upon which was mounted a cathode ray tube (CRT) display. A stereo tape-recorder was used to produce the required error signal. An AC-DC transducer converted the audio signals of the tape into voltage input for the CRT. Each work station contained a handle grip response button for indicating the detection and magnitude of error signals, and also a signal light for requesting relief from watch duty.

## EXPERIMENTAL PROCEDURE

The subjects were scheduled for three sessions of three hours each in the environmental chamber. Although the two-man team spent a total of three hours in the chamber each session, only one subject was on duty at any given time. The other subject would be off-duty and engaged in magazine reading or resting activity, but he was not allowed to leave his chair or otherwise disrupt the subject on duty. Prior to the first experimental

session, subjects were given training in which the task was explained and an opportunity to practice the task was provided. Subjects reported for the experiment between the hours of 10 a.m. and 2 p.m. Subjects were instructed to terminate watch immediately upon feeling they were becoming inattentive or likely to miss the error signal. They could request the other team member to take over the monitoring job by means of the light signal previously described. This procedure was repeated on a self-determined work cycle basis by each subject on duty as he felt he needed a rest break. Thus, the duration of time on duty was determined by the operator himself, but the duration of time on rest was determined by the opposite operator's work period selection. No wrist watches or other cues of external time were allowed during the session. Since the work/rest interval selected was a primary variable of interest, it was necessary that vigilance performance was maintained at the highest level possible. Both a positive and a negative incentive bonus system were used in the payment of subjects in an attempt to provide relevant motivation for high performance. Each team was paid a base rate for performing in the experiment, but penalties of \$5 or \$10 were subtracted from this base if the team operated below specified levels of performance. The teams were also competing for a \$100 bonus which was presented to the team having the highest score on the task.

## RESULTS

A randomized block factorial design analysis of variance was used to evaluate the major independent variables of interest in this study. Neither the temperature (74°, 84°, 90°), sessions (first, second or third), or work period (first or last) showed significant effect on either the selected duty time or on the performance scores. This implies that the self-determined work/rest period allowed a team to choose schedules which minimize the effect of temperature, boredom and fatigue during the work period.

It was also possible to look at sub-groups of the experimental population and evaluate some specific characteristics which were

not apparent when considering the subject population as a whole. The mean on-duty work period selected by the 24 subjects on this experimental task are plotted in Figure 1. The work periods selected appear to fall into three natural grouping of 0 to 24, 25 to 48, and 49 to 72 minutes. Comparison of mean performance scores for each work period are presented in Figure 2. The higher performance scores as associated with the short work period, are significantly higher than for the long work period ($\alpha$ = .05), but not different from the middle length period. This finding is consistent with most vigilance literature which shows performance to normally decrease as a function of time on duty. In this case, though, it should be remembered each operator selected his schedule in an attempt to optimize his own performance score.

Another characteristic of the self-determined work/rest schedule is a tendency for the first time on duty to be shorter than the mean on-duty time. Figure 3 depicts each time on duty during a session and whether the duty is longer or shorter than the mean time for that session. This finding was not anticipated as it was expected that the chosen work period would become shorter as the three hour session progressed in order to counteract any build-up of fatigue or boredom. This was not observed, however. Instead we see a tendency during the first time on duty to select a work period that is significantly shorter than the mean work period time for that session. Possible explanations for this observation are that the first work period required an element of familiarization with the task and with the teammate which tended to cause the subject to be conservative in his selection of a work period. Further, he may have anticipated on his initial work period that the rest break would be more beneficial than it proved to be on subsequent periods.

Several subjective responses were obtained from each subject after completion of the experimentation in an attempt to better understand the nature of self-determined work/rest cycles in the heat. The subjects indicated good ability to estimate length


Figure 1. Mean on-duty work period selected

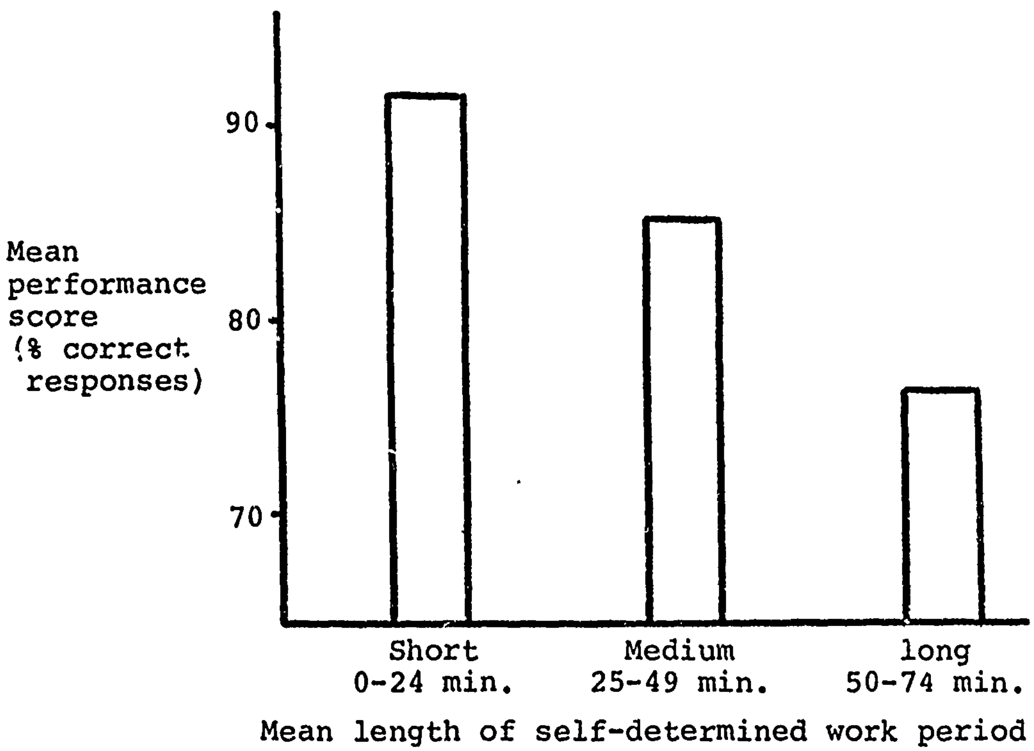



Figure 2. Performance scores for each work period

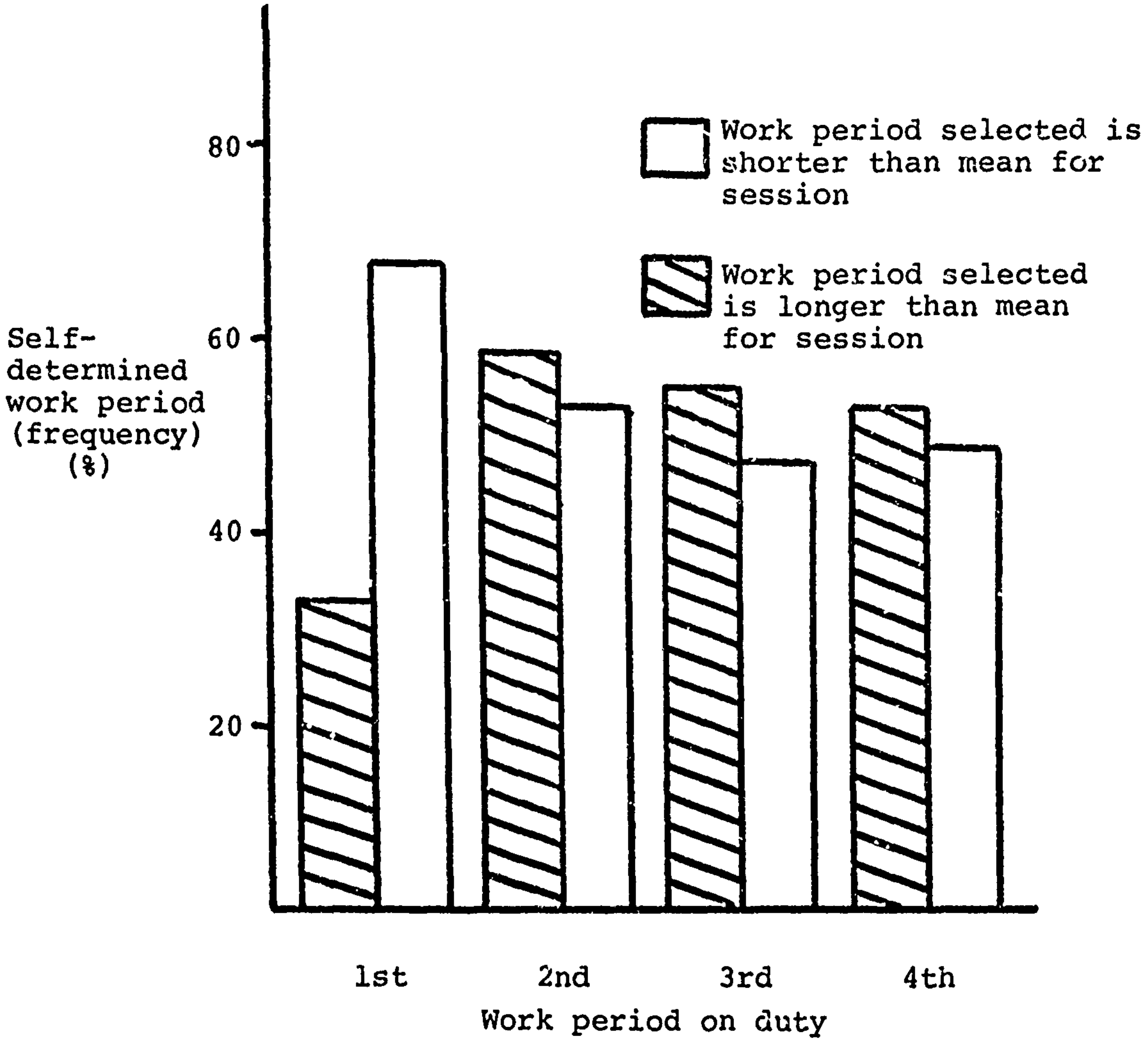



Figure 3. Work period selected relative to mean work period.

of their mean work session. Figure 4 shows the error between actual and estimated on duty time; 54% of the subjects were able to estimate their duty time within $\pm$ 5 minutes. If we delete the four long sessions where time was approximately 1 hour on duty, then we note that on-duty time was estimated correctly within $\pm$ 5 minutes, some 77% of the time. Thus, without watches or outside time cues, most operators could maintain very good estimates of their time on duty. The four subjects who selected long duty times and showed poorer performance scores did not possess the same ability to estimate their on-duty time. This would indicate that one desirable skill for a person using self-determined work/rest schedules would be the ability to estimate their on-duty time and thus avoid the long work periods which tend to result in lower performance scores. Waag (14) also observed a high correlation between vigilance and time estimation ability.

Another interesting factor influencing the selection of a work/rest strategy appears to be how well team members knew one another before the task. Based upon questionnaire responses, the teams were grouped into those who knew one another well and those who did not know one another prior to the session. The mean times selected and average performance were compared on this basis. Although no statistically significant differences were found, it is interesting to note that the four subjects who chose to work on the short period and performed at the correspondingly high level all indicated teammates as "very close friends," whereas subjects who selected the long work periods (55 to 65 minutes) indicated they knew one another "not at all" prior to the experiment. None of these subjects were given prior training or orientation into what type work schedule to select. Their only criterion was to attempt, in their judgement, to find a work/rest schedule which would allow them as a team to maintain a high performance level. This factor is apparently a very important variable which should be considered in future studies of self-determined work/rest schedules.

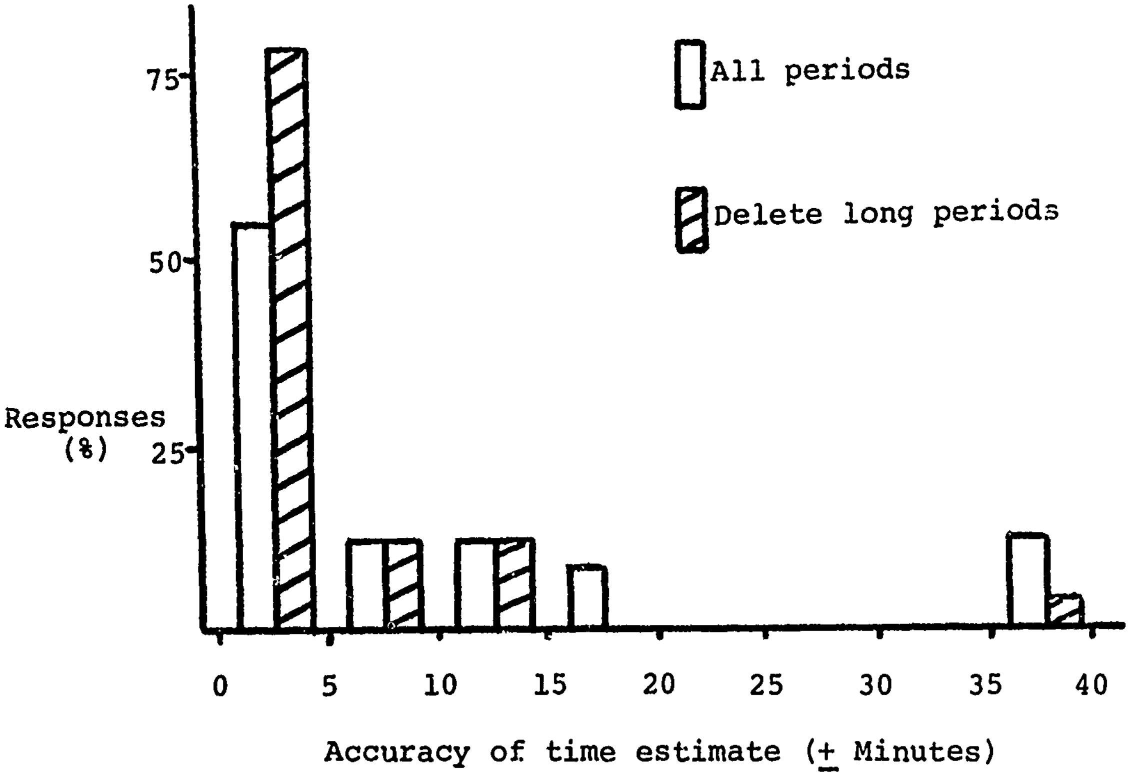
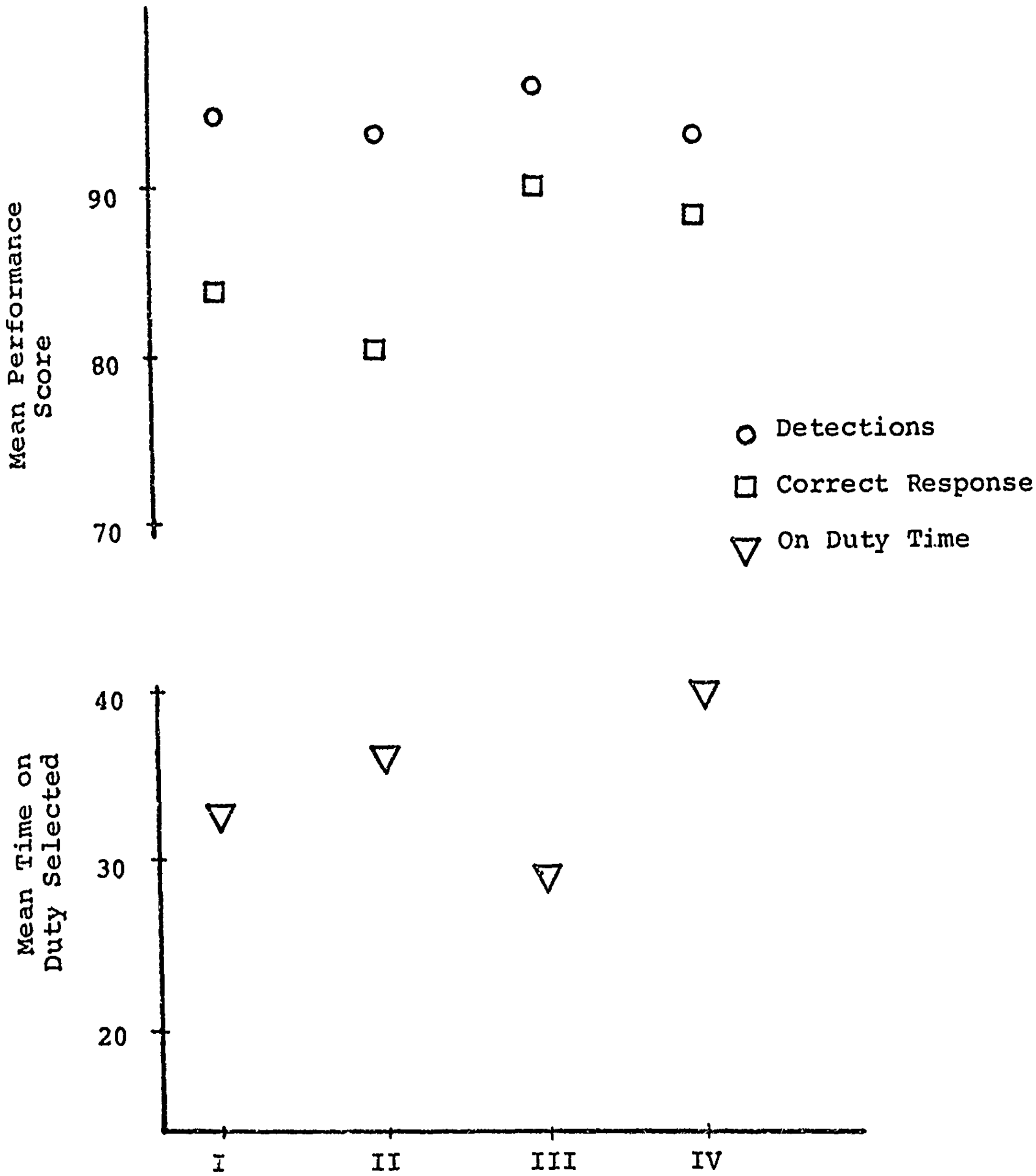



Figure 4. Subjective ability to estimate on-duty time

Since the temperature variable did not show the strong influence on selected duty time or performance as expected, these factors were analysed as a function of the subjects "comfort" or "discomfort." Some subjects reported no uncomfortable temperature sessions and others reported uncomfortable sessions during both warm and hot temperature conditions. However, there were no significant relationships between the time selected or mean error score and the degree of discomfort reported by the operator.

Several other subjective responses were analysed in terms of performance score and/or on-duty time selected. Subjects were given an opportunity to rate their own performance as it compared with other typical subjects on this type task. No subject indicated their performance below average or poor, and there was no consistent relationship between performance and their perceived estimates of their performance. Similarly, subjects were asked how well they liked this type of work task. Again, there was no correlation between actual performance and how well the task was liked. As a matter of fact, some of the poorest scores were performed by people who highly liked the task and conversely some of the best scores came from those who highly disliked the task. Other responses where subjective assessment correlated poorly with task performance, concerned whether or not the subject got drowsy or bored during the watch session. The tendency to either should likely be reflected in selection of a shorter duty period and/or a decrement in performance. Neither relationship was indicated with this data however.

Findings of this analysis can be compared and related to several other studies which have been performed using different subject populations. A self-determined work/rest pilot study has been conducted using female subjects organized into 4 teams and performing the same monitoring task during 3-hour sessions. As seen in Figure 5, the female measures of monitoring activity are not unlike those of the male subjects reported herein, either in mean performance scores or mean time on-duty. A second preliminary study utilized 4 teams of Air Force officers performing




Legend:
Subject population
I. 24 subjects, male, college age, self determined work/rest
II. 8 subjects, female, college age, self determined work/rest
III. 8 subjects, Air Force officers, at midnight, self determined work/rest
IV. 108 subjects, male, college age, pre-specified work/rest

Figure 5. Comparative Performance for Different Subject Populations

the same vigilance task for 2-hour sessions between 10 p.m. and midnight. Selection of the late hour was an attempt to compare the influence of fatigue and increased drowsiness at the end of the day on the performance and work/rest schedules. However, since this subject population was highly proficient at this type task, no decrement in performance or difference in duty period was observed when compared to the other experimental data in Figure 5.

A comprehensive study using the same experimental equipment and monitoring task was reported by Mortagy (11) who utilized 108 subjects to perform this task over 3-hour sessions. In this investigation, however, the duration and work/rest schedule were fixed for each operator and there was no self determination of their schedules. Only the combination conditions of high temperature (90°FET), long work periods (60 minutes), and short rest cycles (3/1 work/rest) yielded a major decrement in vigilance performance in this study. The mean performance level and mean duty time used are not significantly different from those of the self-determined studies as shown in Figure 5. This observation raises the question whether self-determined work/rest schedules are actually preferable to a fixed schedule that allows rest intervals at some reasonable (20 to 40 minutes) duration. Data from this self-determined cycle study shows that two-thirds of the persons performing this watch selected, without external times cues, a work period of 20 to 40 minutes.

## CONCLUSIONS

In summary, allowing the subject to select at his own will a self-determined work/rest schedule to optimize his performance, has some limitations as an operational procedure. Although this procedure did seem to minimize any major temperature, session work period effects on performance, these effects are not different from those found when specified or dictated schedules for work of this general duration are followed.

The subject choosing "long" sessions to optimize his performance scored significantly poorer than his peers. Similarly, those

selecting long sessions showed less ability to accurately judge their time on-duty. The subjects in general did a poor job of relating their own thermal discomfort, drowsiness, boredom, estimate of job performance and like or dislike for the job to their actual performance score and/or time on-duty which was selected.

Thus it is suggested that using a self-determined work/rest procedure may be a useful way to establish a desirable schedule for performing a task. However, after this is established, a specified work/rest schedule could be utilized to avoid those operators who would choose inappropriate schedules. Such a specified schedule would yield equivalent overall performance, but with a simplification in operational controls required.

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## DISCUSSION SESSION

## J. D. RAMSEY

LEON KATCHMAR: What was the signal frequency?

J. D. RAMSEY: It was four signals per ten minutes, and they were randomly distributed, between a half-minute and five minutes apart. The signals were presented in even ten-minute units. Every ten minutes there were exactly four signals presented. So there could have been some leeway--some possibility of a subject in a ten-minute period being presented with only two or three signals. The subjects were both in the test chamber for three hours; one of them was "on duty" at all times. "Time on duty" represents just that. Every ten minutes as a team their average time of transfer was ten minutes. They both had exactly the same 180 minutes of exposure to the signals and the same full number of signals.

Then, another characteristic of the self-determined work schedule was the tendency for the first period of time on duty to be shorter than the mean on-duty time. We did not see this in any of the subsequent sessions: there was no dominant tendency, no statistical difference as to whether or not they chose a shorter or a longer work period. This was contrary to what we expected. We had expected that early in a session the subjects would be more fresh (e.g., not as tired or bored) and would choose a longer work period. From the subjects' statements, the results seem to be due to getting familiar with the task and the social interaction with their teammates.

Another thing we noted was that the subjects indicated a very good ability to estimate the length of their mean work session. More than half the subjects were able to estimate their mean on-duty time within plus or minus five minutes.

ED BURKHART: How did you provide motivation for the subjects to perform at a high level?

J.D. RAMSEY: We had both a positive and a negative incentive. We paid the subjects a base rate, and the negative incentive was a deduction of five to ten dollars if they scored below the criterion. In terms of a positive incentive, we paid a $100 bonus for the two-man team that performed best.

R.A. DUDEK: Did you notice whether if the first subject chose a short on-duty period the crew stayed on a short rotation cycle for the whole time? Or, if he picked a long duty period was his partner prone to also choose long periods?

J.D. RAMSEY: There did appear to a dominant subject in each group, one whose choice of on-duty time tended to set a pattern for the team, but it wasn't necessarily the first subject to perform.

CLAY GEORGE: It looks like if you had two soldiers out on an observation post and they are good friends, they are probably going to alternate observing fairly frequently and do a better job overall, than would a couple of guys who were strangers and alternated after longer time periods.

J. D. RAMSEY: I think this matter of familiarity should be investigated further. There also was an element of communication off the task that we could not control for.

CHARLES G. HALCOMB: Remember, this study was performed over a period of days, so the people who were friends were much more likely to have worked out a strategy.

J. D. RAMSEY: Yes, that's true, but we didn't encourage that.

LOUISE B. SPECK: I have a question about the procedure. If I were the subject and my partner is working (I'm resting), is the only signal that I have that it is time to go to work a red or green light?

J. D. RAMSEY: Yes.

LOUISE B. SPECK: Well, then I have to work during my rest, because I have to monitor my button. I can't read a magazine or do exercises. It is not really rest to me; it would be work of a different kind--I have to monitor which is not resting.

J. D. RAMSEY: And you have to sit in the heat.

LOUISE B. SPECK: Right, and so I have a question about whether or not there was any rest going on at all?

CLAY GEORGE: This bears on one of our explanations for the results. One of the reasons for the longer work periods is that after the subject has experienced one of the "rest" periods they may have much less to offer him!

LOUISE B. SPECK: Right. I would just as soon monitor my button as sit and wait for my turn to go to work.

BEN B. MORGAN, JR.: I would like to see an experiment run in which a crew has to maintain a high level of performance, say 95 percent, for 24 hours. One subject would be in the chamber under stress while the other subject is outside resting. He could even be sleeping, and a buzzer could be used to wake him. It would be interesting to see what sort of cycle or schedule they worked out under these conditions. Also, whether the subject can monitor his own performance well enough to know when to call in his teammate.

JAMES H. BANKS: What happens if one subject wants to rest and the other didn't want to work?

J. D. RAMSEY: We found termendous social pressure and a good ability to estimate time. We didn't find one subject working for ten minutes and his partner working for an hour.

# Applicability of Research on Sustained Performance, Endurance, and Work-Rest Scheduling to the Development of Concepts and Doctrine of Continuous Operations

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ABSTRACT.--The research program of the Performance Research Laboratory is primarily concerned with the assessment and enhancement of complex human performance. One of the specific aims of this program has been to study the effects of work-rest schedules, circadian rhythms, continuous work, and sleep loss on work behavior or sustained performance. A description of this line of research, including a discussion of the synthetic-work methodology and the multiple-task performance battery (or MTPB) that is the foundation of that methodology, is presented. Some of the more important findings of this research are also presented, and the applicability of these findings to the requirements for continuous operations is discussed.

## INTRODUCTION

The Performance Research Laboratory was established formally in September 1968, as one of the several Institutes for Advanced Studies in the Graduate School of the University of Louisville. The stimulus for its formal organization was the award of an Army THEMIS Contract (No. DA HC19-69-C-0009) monitored by the U. S. Army Behavior and Systems Research Laboratory in Arlington, Virginia. The research mission of the Laboratory is given in the title of its Army THEMIS Contract; namely, to conduct "Studies of Performance Assessment and Enhancement." Thus, under support from the THEMIS Contract, as well as several other smaller grants and contracts, we have tried to advance a single, cohesive, and comprehensive program of research on the assessment and enhancement of human performance.

This program of research currently calls for sustained-performance experimentation to be conducted in four specific areas; namely, experimental studies of (a) endurance and work-rest scheduling, (b) illness and organismic stresses, (c) forced rest and sleep-wakefulness cycling, and (d) other environmental, task, and situational stresses. While this paper will deal primarily with the first of these areas--studies of endurance and work-rest scheduling--we need first to say a word about the importance of these areas and their relations to one another.

One of the principal aims of our research has always been to study the effects of temporal variables such as work-rest schedules, sleep-wakefulness cycles, circadian rhythms, continuous work, and sleep loss on work behavior or sustained performance. We consider this work to be of special importance because its objective bears a direct correspondence to the Department of the Army's current interest in developing a capability for continuous operations by division of higher-level units. In November of 1969, Col. Marks of the U. S. Army Combat Developments Command called for research to determine "the length of time (hours, days, weeks) a unit can perform its primary mission effectively before it must be relieved, plus the length of time before it is

operationally ready for commitment again," (18). Our studies of continuous work, sleep loss, and the recovery of performance are directly related to these needs.

Our goals have to do not merely with the assessment of performance, but also with its enhancement. If there are work-rest schedules that can be used to enhance performance, we should know about them. Obviously, the scheduling of work and rest is one of the things we can do (in or out of the military services) to increase efficiency without injury to our National conscience; we might also consider the use of drugs to enhance performance, but such an approach would probably not win wide acceptance among Americans.

Also, the question of work-rest scheduling is going to become of much broader interest, it seems to us, not only as the military services, public utilities, and certain other operations (principally in the recreational and service lines), but also as the business, commercial, and industrial communities more generally begin to extend their hours to the limit of continuous, 24-hours-a-day, 7-days-a-week operations. We believe this extension is inevitable, given the increasing pressures on our National facilities and the inefficiency represented by our keeping these facilities closed more hours than open. Thus, the questions related to the scheduling of workers so as to maintain continuous operations, and to do so efficiently with an optimum enhancement of performance, are of increasing importance.

One does not begin to look at endurance and work-rest scheduling, however, without being forced to consider man's typical diurnal rhythms, his activities during the "rest" portions of the schedule, and the effects of his sleep-wakefulness cycles and habits on performance (cf. 21). Likewise, the effects of illness on work behavior is of interest not only in its own right, but also because it can provide some indication of the relations between the psychophysiological or biomedical variables that are assumed to mediate, if not "cause" man's behavior, and the behavior itself. Finally, if such studies serve to provide behavioral assessments of the incapacitating effects of certain illnesses, and, therefore, assessments of the vulnerability of man's behavior to disturbances by infectious diseases, it should also be possible to assess the effects of other stresses in the same way, to relate different stresses in terms of the degrees of disturbances created and to devise methods of minimizing decrements and enhancing performance. Such are the general areas and goals of our current research program.

## METHODOLOGY

The methodological basis of our research is the synthetic-work approach (2,3,13) which has been developed for use in the investigation of work behavior or sustained performance.

## Sustained Performance

By "sustained" performance we mean the more-or-less continuous performance of tasks, sets of tasks or jobs, during 4 or more hours a day over a period of weeks, months, or even years. Such performances belong to the domain of work behavior; they differ from the test behaviors more often studied by psychologists.

The tasks presented in typical test situations tend to be simple and unitary, to depend on single channels of sensory input and motor output, and to be scored in terms of speed and accuracy. On the other hand, the tasks that comprise job or work situations are typically complex and multidimensional, demand the time-sharing of many different stimulus and response elements, but unfortunately provide no easily identified criteria with which the performance obtained can be assessed (12,14). Relative to the highly skilled performances of experienced workers, the behavior observed in most test situations is essentially unskilled. A person's motivation and general behavior are likely to be different in test and work situations, and so are his apparent reactions to stressful conditions such as sleep loss and illness.

## Synthetic Work

The synthetic-work approach (2,3,13) provides measurements of multiple-task performance obtained in the work-behavior domain. The job or work situation is created by a synthesis of several time-shared tasks that represent functions which man is called upon to perform in just about any job. It is a compromise between the use of full-scale simulation on the one hand, and specific-test techniques on the other. It provides less face validity, but greater generality than full-scale, integrated, mission simulation (cf. 16,17); it provides more face validity at the price of less well established content validity than the best of the factor-analytically based specific-test techniques (cf. 1 ,19). Basically, it provides a job situation in which men work at realistically high levels of skill and with realistically varying levels of work load. Several similar multiple-task performance batteries have been used in the synthetic-work approach to the study of sustained performance; the front view of an operator panel in the MTPB used at the University of Louisville is shown schematically in Figure 1.

Behavioral measures are obtained from the operator's performance in working at the six tasks presented with the panel. The tasks are generally displayed at each of five identical work stations--one for each member of a 5-man crew. Three watchkeeping tasks are used to measure the performance of watchkeeping, vigilance, and attentive functions (warning-lights, blinking-lights, and probability monitoring). Three active tasks are used to measure the performance of memory functions (arithmetic computations), sensory-perceptual functions (target identifications), and procedural functions (code-lock solving). Communication functions are not measured directly, although they are involved to some extent in the performance of all three active tasks.

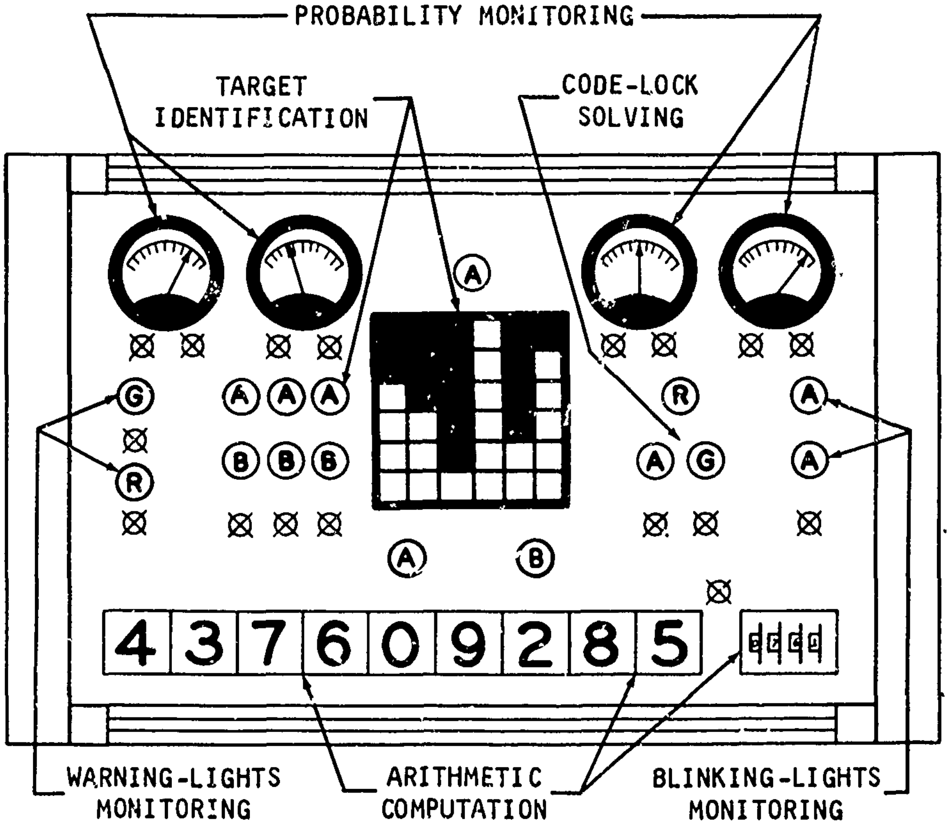


Figure 1.--Schematic diagram of the front view of an MTPB operator panel. Letters in circles represent indicator lights, A--amber, B--blue, G--green, and R--red; the smaller circles with crossing diagonals represent push buttons.

Tasks designed to measure directly certain nonverbal-mediational aspects of intellectual functioning (cf. 8,9), and a kind of decision-making behavior (cf. 22) are under development. Some attempts have been made to employ tracking tasks with MTPB (e.g., 1,11).

Detailed descriptions of the MTPB have been published elsewhere (cf. 3,13). All of the tasks show very high reliabilities (4,5,13,20), and have done so since their earliest use (1). For further details, the papers cited should be consulted, especially the three summary papers (3,4,13).

The six tasks are synthesized with the panel and work schedule into a reasonably realistic work-like situation--a situation that requires the operator to be responsible for the time-sharing of functions at various levels of work load. The work is typically divided over a 2-hour performance period so that the operator is responsible all of the time for the three watchkeeping tasks, but only part of the time for the three active tasks: (a) arithmetic computations during 30 minutes of each 2-hour

period, 15 minutes in combination with the watchkeeping task only, and 15 minutes with the group-performance procedural task of code-lock solving as well, (b) code-lock solving during half of each 2-hour period, 15 minutes with arithmetic computations and watchkeeping, 30 minutes with watchkeeping alone, and 15 minutes with watchkeeping and target identifications, and (c) target identifications during 30 minutes, half as indicated (with watchkeeping and code-lock solving) and half with the watchkeeping tasks only. Thus, relative demands on performance are low, intermediate, or high, depending on whether the watchkeeping tasks are presented alone, with only one of the active tasks, or with two (or more) of them. The 2-hour performance schedule typically used is shown in Table 1.

TABLE 1

Basic 2-Hour Task-Performance Schedule

| Performance Task | 15-Minute Interval in Each 2-Hour Period | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Blinking-Lights Monitoring | X | X | X | X | X | X | X | X |
| Warning-Lights Monitoring | X | X | X | X | X | X | X | X |
| Probability Monitoring | X | X | X | X | X | X | X | X |
| Arithmetic Computations | | X | X | | | | | |
| Code-Lock Solving | | | X | X | X | X | | |
| Target Identifications | | | | | | X | X | |
| Level of Demand | Low | Med. | High | Med. | Med. | High | Med. | Low |

## FINDINGS: SOME INTERPRETIVE RESULTS

In the presentation of the results of studies conducted in this program, data will be taken from numerous individual studies--studies that really comprise four separate series. In order to help you in identifying the individual studies and their characteristics, they have been listed in Table 2. We have included as "background studies" several of the experiments conducted during the early 1960's at the Lockheed-Georgia Company, Marietta, Georgia, under USAF support. All of the other studies have been conducted by the Performance Research Laboratory of the University of Louisville.

We shall not present the results of these studies in the chronological order in which they were conducted, but rather we shall present the findings or "interpretive results" of these studies. By "interpretive results" we mean results--data--that lend themselves to interpretation beyond the questions they answered--data that tend to enlarge the state of the art and provide fruitful guidelines for future research efforts. We

TABLE 2

LIST OF BACKGROUND AND MAJOR UL-PRL STUDIES OF SUSTAINED PERFORMANCE

| STUDY | CONDUCTED | SUBJECTS | DURATION AND WORK-REST SCHEDULE | PRINCIPAL VARIABLES | REPORT | PSYCHOLOGICAL LITERATURE |
|---|---|---|---|---|---|---|
| Background: Human Operator Performance Efficiency (HOPE Series) | | | | | | |
| HOPE-III | 1962 Lockheed-Ga. Co. | 10 USAF Pilots | 30 days 4-4 | Confinement | USAF AMRL TDR 63-87 | Hum. Factors 1968, 10, 143-196 |
| HOPE-IV & -V | 1963 Lockheed-Ga. Co. | 20 USAF Pilots & Acad. Cadets | 12 days 4-4 | 44-hr Sleep Loss | USAF AMRL TDR 64-63 | Hum. Factors 1968, 10, 143-196 |
| HOPE-VI & -VII | 1963 Lockheed-Ga. Co. | 12 USAF Pilots | 12 days 4-2 | 40-hr Sleep Loss | USAF AMRL TDR 64-63 | Hum. Factors 1968, 10, 143-196 |
| Studies of Performance Assessment and Enhancement (SPADE Series) | | | | | | |
| SPADE-1 | 1970 Univ. of Louisville | 10 ROTC Cadets | 15 days 4-4-4-12 | 48-hr Continuous Work & Sleep Loss | UL-PRL ITR-70-16 | |
| SPADE-2 | 1971 Univ. of Louisville | 10 ROTC Cadets | 15 days 4-4-4-12 | 36-hr Continuous Work & Sleep Loss | In Prep. | |
| Behavioral Effects of Infectious Diseases (BEID Series) | | | | | | |
| BEID-1 | 1965 Univ. of Louisville | 10 ROTC Cadets | 12 days 4-4-4-12 | Control | UL-PRL ITR-67-6 | Percept. & Mot. Skills 1971, 32, 647-668 |
| BEID-2 | 1966 Ft. Detrick | 10 Army Med. Corpsmen | 12 days 4-4-4-12 | Tularemia | UL-PRL ITR-67-6 | Percept. & Mot. Skills 1971, 32, 647-668 |
| BEID-3 | 1966 Ft. Detrick | 10 Army Med. Corpsmen | 15 days 4-4-4-12 | Tularemia | UL-PRL ITR-68-8 | In Press |
| BEID-4 & -5 | 1967 Ft. Detrick | 20 Army Med. Corpsmen | 15 days 4-4-4-12 | Phlebotomus Fever | UL-PRL ITR-69-10 | In Press |
| BEID-6 | 1969 Ft. Detrick | 10 Army Med. Corpsmen | 15 days 4-4-4-12 | Phlebotomus Fever With Strength and Endurance Measurements | UL-PRL ITR-70-14 | In Prep. |
| BEID-7 | 1970 Ft. Detrick | 10 Army Med. Corpsmen | 15 days 4-4-4-12 | Phlebotomus Fever With Symptomatic Treatment | In Prep. | |
| BEID-8 | 1971 Univ. of Louisville | 10 ROTC Cadets | 12 days 4-4-4-12 | Symptomatic Treatment Alone | In Prep. | |
| Behavioral Effects of Interrupted Recovery (BEIR Series) | | | | | | |
| BEIR-1 | 1971 Univ. of Louisville | 10 Volunteer Students | 12 days 4-4-4-12 | 44 hr Cont. Work/4 hr Recovery | In Prep. | |
| BEIR-2 | 1971 Univ. of Louisville | 10 Volunteer Students | 12 days 4-4-4-12 | 36 hr Cont. Work/4 hr Recovery | In Prep. | |
| BEIR-3 | 1971 Univ. of Louisville | 10 Volunteer Students | 12 days 4-4-4-12 | 36 hr Cont. Work/3 hr Recovery | In Prep. | |
| BEIR-4 | 1971 Univ. of Louisville | 10 Volunteer Students | 12 days 4-4-4-12 | 36 hr Cont. Work/2 hr Recovery | In Prep. | |

shall also not attempt to present results from all these studies, nor all the results from any particular study, but rather we shall present only those findings that are relevant to the development of concepts and doctrine of continuous operations.

Where 8 = 12

Figure 2 presents the percentage of correct responses in the arithmetic-computations task, when time-shared with three watchkeeping tasks, but without concurrent presentation of code-lock solving. The data of two groups of subjects, from different experiments (and slightly different versions of the MTPB), are presented. The broken line (HOPE-III) shows the data of the first 12 days of performance of 10 USAF Officers, all pilots, who followed a work-rest schedule of 4-hours on-duty and 4-hours off for 30 days while confined to a crew-compartment mock-up in the Human Factors Research Laboratory of the Lockheed-Georgia Company (7). The dotted line (BEID-1) shows the data of 10 AFROTC cadets who followed a work-rest schedule of 4-hours on-duty, 4-hours off, 4 on, and 12 off, in an 11-day control study conducted when school was not in session at the University of Louisville (10). In both cases, the subjects were divided into two, 5-man crews, so that the MTPB was operational for continuous periods of 24 hours per day in the first case, and 16 hours per day in the second.

It is apparent from the data of Figure 2, as it was in all the data obtained, that the two groups performed at essentially identical levels. Thus, the 4-4 work-rest schedule under the conditions of the 30-day study (i.e., with controlled environmental conditions and demands) produced performances that were as good as those obtained with the less demanding 4-4-4-12 schedule under conditions in which the operators or subjects were free during their off-duty hours to interact with their normal environment and the typical demands of that environment.

Thus, performance efficiency can be maintained at a high level with men working as much as 12 hours a day on a 4-4 schedule, if other conditions are arranged appropriately. Previous indications of increased efficiency's being obtained with 8-hour work days relative to longer 10- or 12-hour work days (cf. 21) apply to the conditions in which off-duty time must be spent in such "housekeeping" functions as going to and from work, doing the shopping, and mowing the lawn.

This also means that as extra-curricular demands are increased (and they seem always to be increasing in our modern work load), the total work periods and work-rest schedules may have to be modified to obtain optimum performance efficiency. The civilian world may be heading toward a 6-hour day, with a split-shift schedule of 3-hours on-duty, 3-hours off, 3 on, and 16 off, or a shorter 4-day work week and longer 10-hour work day, especially as the business day lengthens and we approach continuous operations.

For short periods of time, in emergencies, and when extra-curricular demands are reduced or ignored, there is no question concerning man's abilities to work 12 or 16 hours per day, and with a maintenance of high

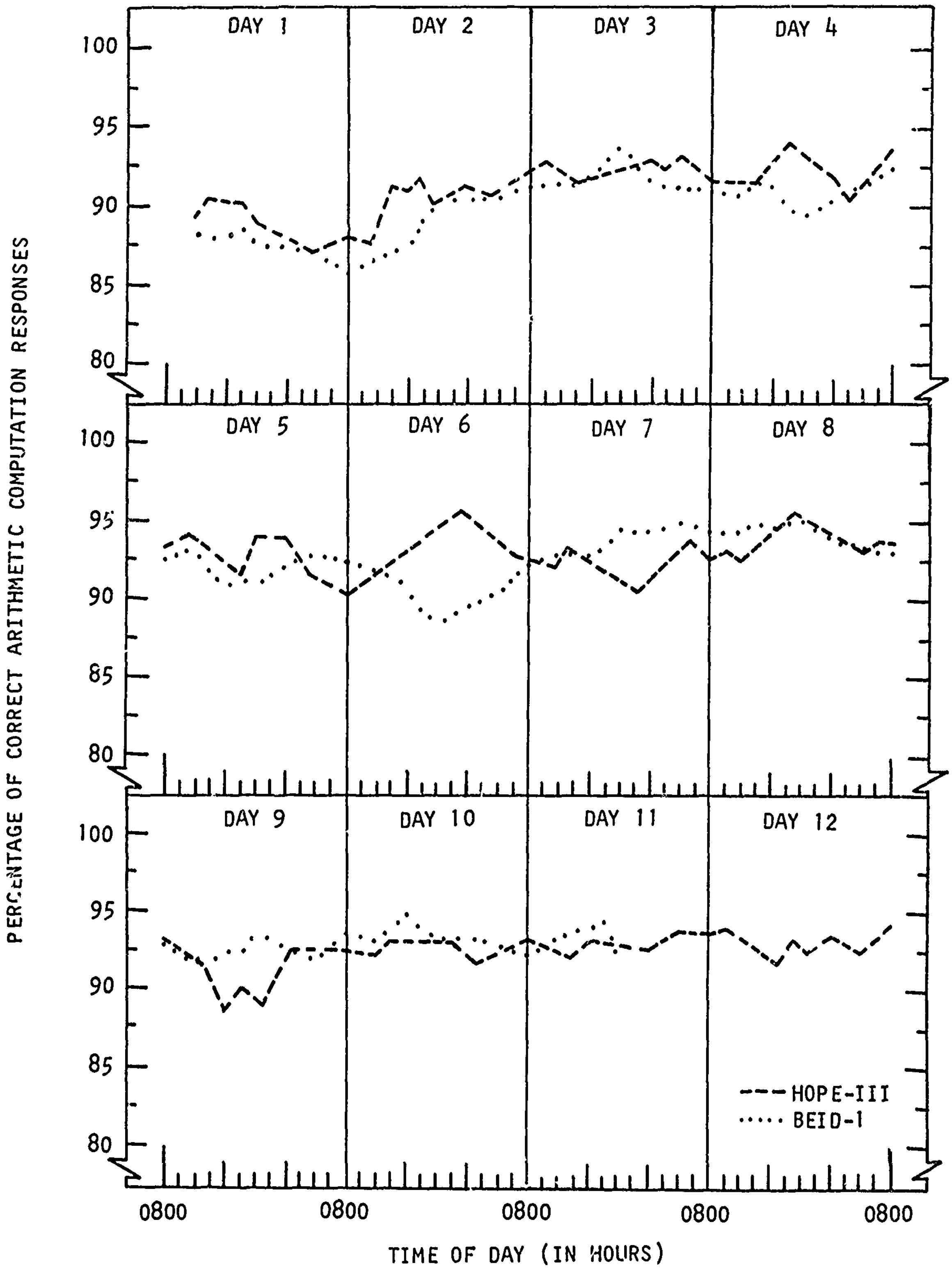


Figure 2.--Average percentage of correct responses to arithmetic-computation problems by a 10-man control group (BEID-1) and a 10-man experimental group (HOPE-III) working 8 and 12 hours per day, respectively (data of 7,10)

levels of performance efficiencies. As part of the job of planning for the efficient, satisfying, and honorable employment of man we will certainly have to consider work-rest scheduling, durations of work within day, week, month, and longer periods, and the extra-curricular "housekeeping" demands made on all of us.

## Training: Distributed and Massed

The MTPB tasks have been selected so as to require very little training. Individually, the tasks are performed at close to asymptotic levels after relatively brief familiarization training. However, the time-sharing of the tasks, i.e., their proper combination into a single, unitary "job," must be learned by the MTPB operators. Our past experience has shown that this requires on the order of about 48 hours of practice, or the equivalent of six 8-hour days of work.

We have not always worked subjects the same number of hours per day. For example, in HOPE-VI and HOPE-VII the operators worked 16 hours per day on a 4-2 work-rest schedule, whereas in the BEID-1 control study they worked 8 hours per day on the 4-4-4-12 schedule. In the SPADE-1 study, the Ss were trained only 12 hours per week; they were employed in the Laboratory for 20 hours per week, with three 4-hour periods of work having been established for operating the MTPB panels. In Figure 3, we have combined the SPADE-1 data in such a way that each "day" represents 8 hours of MTPB operation, so the data are comparable to the data of the BEID-1 group which actually did work 8 hours on each of 6 successive days. The data of the HOPE groups are those of the first 6 days of the study and represent actually twice as much practice as that shown in the other two groups. The measure is the mean percentage of baseline performance, a general index of performance that includes all 13 of the behavioral measures derived from the individual-performance MTPB tasks.

It is evident that the three groups are essentially identical. The distribution of practice appears to be less important in the learning of the time-sharing skills required than the adoption of the proper attitude by the subject, i.e., than his acceptance of the situation as one of "work" rather than of play or testing.

## The Circadian Rhythm

Underlying man's activities, there is a biological or psychophysiological circadian rhythm which is at least to some extent conditioned by those activities. Such a rhythm is shown in the axillary-temperature data of Figure 4. These are data of the 10 USAF pilots who followed a 4-4 work-rest schedule for 30 days (HOPE-III; 7). The solid line presents the data of the first 15 days, and the broken line the second 15 days.

Incidently, until the study ended on the 13th day, these subjects expected it to continue to a total of 40 days, so typical "end effects" should not be present in their data. Also, the effects of individual differences and work activities have been removed by use of a rolling-mean technique; each data point in Figure 4 has represented in it all 10

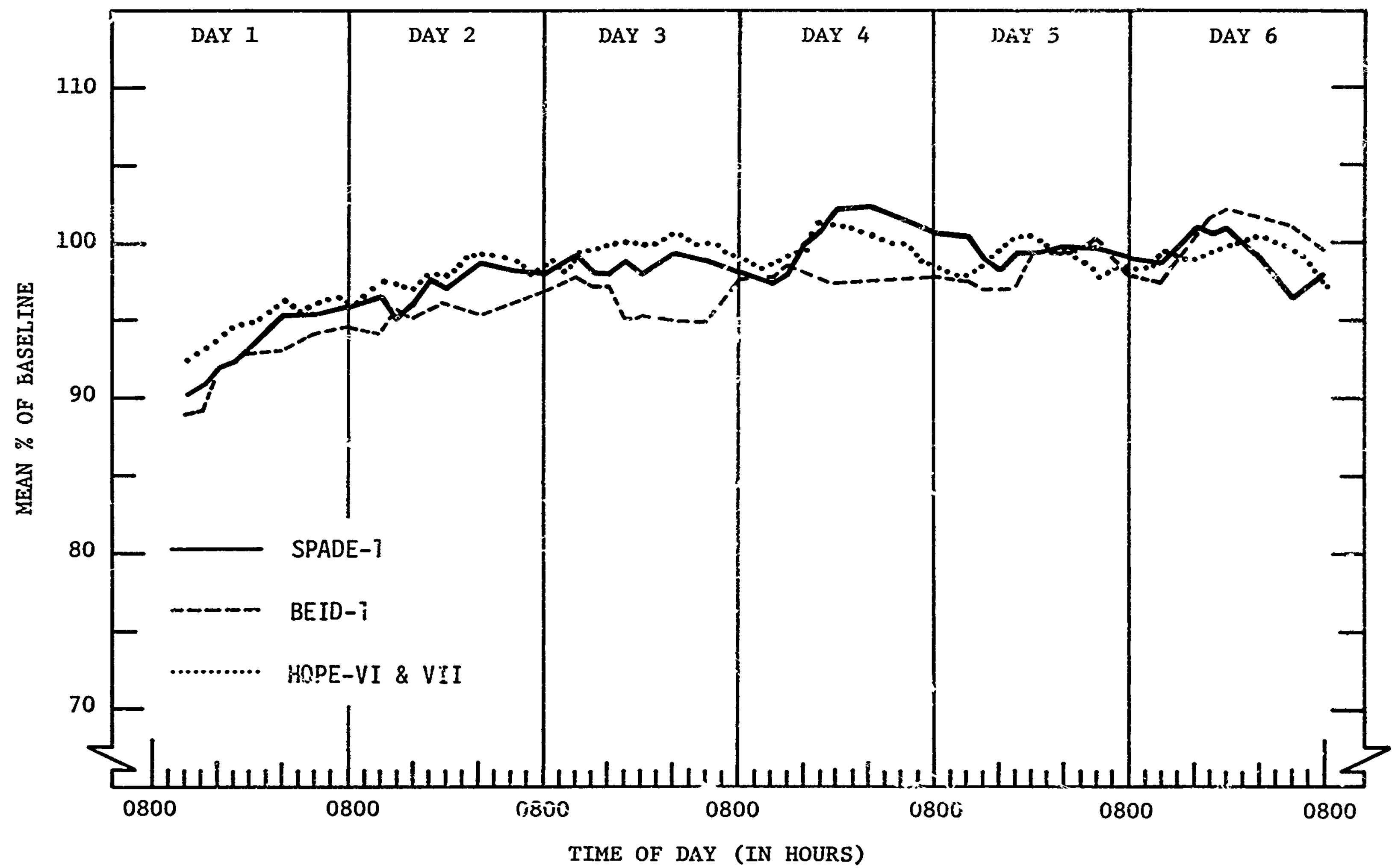


Figure 3.--Mean percentage of baseline performance for the first 6 days of three groups of subjects following different work-rest schedules. Ten subjects worked 4 hours per day, 3 days a week (SPADE-1), 10 subjects worked 8 hours per day on a 4-4-4-12 schedule (BEID-1; data of 10), and 20 subjects worked 16 hours per day on a 4-2 schedule (HOPE-VI and -VII; data of 6).

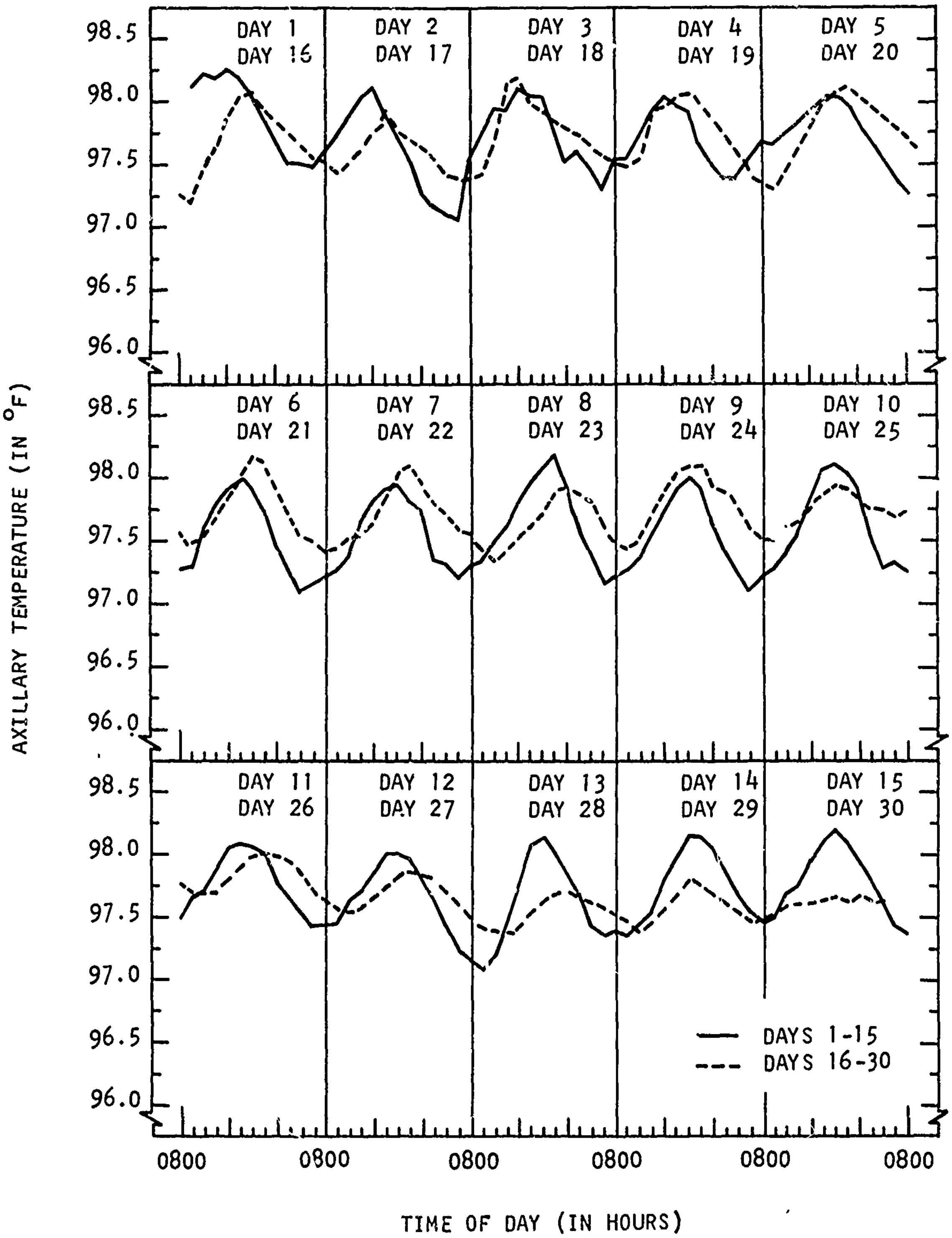


Figure 4.--Average axillary temperatures of 10 subjects (HOPE-III) during 30 days of sustained performance on a 4-4 work-rest schedule (data of 7).

subjects, and equal numbers of measures based on temperatures taken just after having gone on duty, in the middle of a 4-hour duty period, and after having completed 4 hours of duty.

Thus, the curves shown in Figure 4 reflect the "uncontaminated" or "underlying" psychophysiological rhythms; we stress this point for we find frequently made, the error of failing to distinguish this sort of curve from one that includes the effects of the <u>activity</u> as well as the body rhythms.

Several results are indicated by the data of Figure 4. First, the circadian cycling of axillary temperature is clearly evident. Secondly, it should also be evident that the period of this cycle is slightly longer than 24 hours. Thirdly, the cycling clearly continued without much abatement for the first 20 or 25 days before becoming somewhat flattened (statistically significant only during the last 5 days).

Now, with regard to these results, we have found that <u>performance</u> may show the same sort of rhythm, with a lag of about 2 hours or so, depending on certain other factors. The periodicity is greater than 24 hours; this has also been found in other studies of work-rest scheduling with persons working on a 4-2 schedule (cf. 3,13). The points of peak activation (and performance) seem to slip about 2 hours every 5 days or so.

This could mean either or both of at least two things: (<u>a</u>) man's typical 24-hour periodicity results from his having a longer "natural" rhythm which is kept synchronized by his usual 24-hour activity rhythms--analogous to a slow-running clock that is reset every day, or (<u>b</u>) the longer cycle could be simply a secondary indication of the "fatigue" created by the stress of the work load--it takes a little longer to get started each day!

The continuation of the cycling suggests that biological or psychophysiological adaptation to atypical work-rest schedules will take at least 20 days, and perhaps as long as 25 or 30 days on the average. There are indications in the literature (21) that individuals vary widely in their ability to adapt both behaviorally and biologically to changes in the work-rest schedule, and someone should be doing research to identify the correlates of these differences so that men can be appropriately selected and perhaps even trained for missions in which adaptation of this sort is important.

In this regard, it is our own experience that probably the most important factor is the extinction of the old rhythm. Since it is obviously easier for a person to work when he is tired than for him to sleep when he is alert, the adaptation will be enhanced if he can start on the new sleep cycle immediately. Probably the best way to maximize the likelihood of this is to have the person stay awake sufficiently long to assure his being in a low-alertness condition when the sleep period of his new schedule comes around. This is a relatively simple solution to the problem of adaptation to new schedules, but it seems to work very nicely.

Circadian Rhythms, Performance Reserves, and Work-Period Demands

In normal situations man is able to exert extra effort (provided that he is motivated to do so), and thereby overcome the effects of the circadian rhythm on his performance; i.e., he has at his command what we call performance reserves, which may be employed during periods of emergency or low physiological activation. During periods of stress, however, this performance reserve (or the store of "extra energy") is depleted in meeting the demands of the situation, and performance is then limited by its interaction with the underlying circadian rhythm. The interaction of performance with the circadian rhythm is evidenced in the data from SPADE-1 presented in Figure 5.

These data represent the mean percentages of baseline performances for each of the 12 days in SPADE-1 (solid line); comparable data from BEID-1 (dashed line) are also presented as control data. The 48-hour period of continuous work and the occurrence of the 24-hour rest and recovery period are shown on the figure, as is also the day-long interval (the 40th through the 48th hour of work) used as a baseline in computing the mean percentage of baseline.

After training, the 10 SPADE-1 subjects worked for 2 days according to the 4-4-4-12 schedule. They were then required to work continuously for 48 hours, were allowed 24 hours of rest and recovery, and were required to return to work the 4-4-4-12 schedule for 2 days. The results of this study indicate, among other things which will be discussed in detail later, that the diurnal cycling of performance is quite apparent during the 48 hours of continuous work and sleep loss. Thus, while performance may or may not follow the diurnal cycle during normal work periods, it is likely to do so during periods of continuous operations.

We have found, however, that during periods of extended work, man's performance not only interacts with the underlying circadian rhythm, but also with the total demands of his work activity and with the prior expenditures of his performance reserves. These points are illustrated in the data of the three studies shown in Figure 6.

The dotted line represents the data of SPADE-1. These subjects worked 8 hours per day during Days A and B on a 4-4-4-12 schedule. During Days C and D they worked continuously for 48 hours; they were then off-duty for 24 hours, and on Day E they came back to work the 4-4-4-12 schedule for 2 days. It may be noted that their average performance dropped to about 67% of baseline toward the end of the 48-hour period of continuous work, but the 24-hour rest period was sufficient to permit recovery back to between 94% and 101% of baseline on the 2 final days of the study. As stated above (cf. Figure 5), the presence of a diurnal cycling effect is quite evident in the performances of this group during the 2 days of continuous work and sleep loss.

The solid line represents the data of two groups (20 subjects) who worked 12 hours per day on the tasks of the MTPB by following a work-rest schedule of 4-hours on-duty, and 4-hours off, around the clock for a 12-day period. The broken line represents the data of another two groups (12 subjects) who worked 16 hours per day on a 4-2 work-rest schedule for 12 days. At the beginning of the 6th day of these studies,

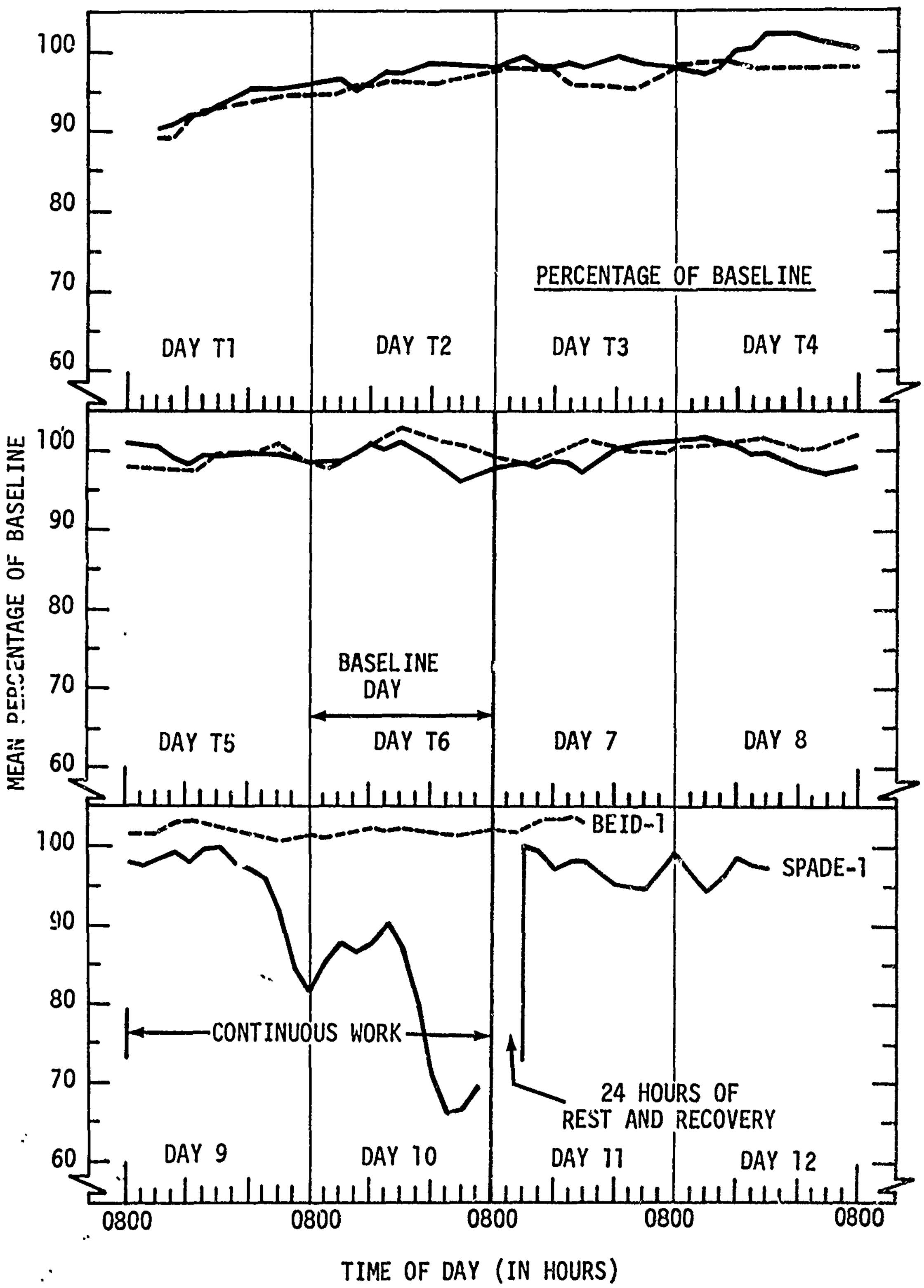


Figure 5.--Mean percentage of baseline performance, an index of general performance, of the BEID-1 and SPADE-1 subjects (data of 19).

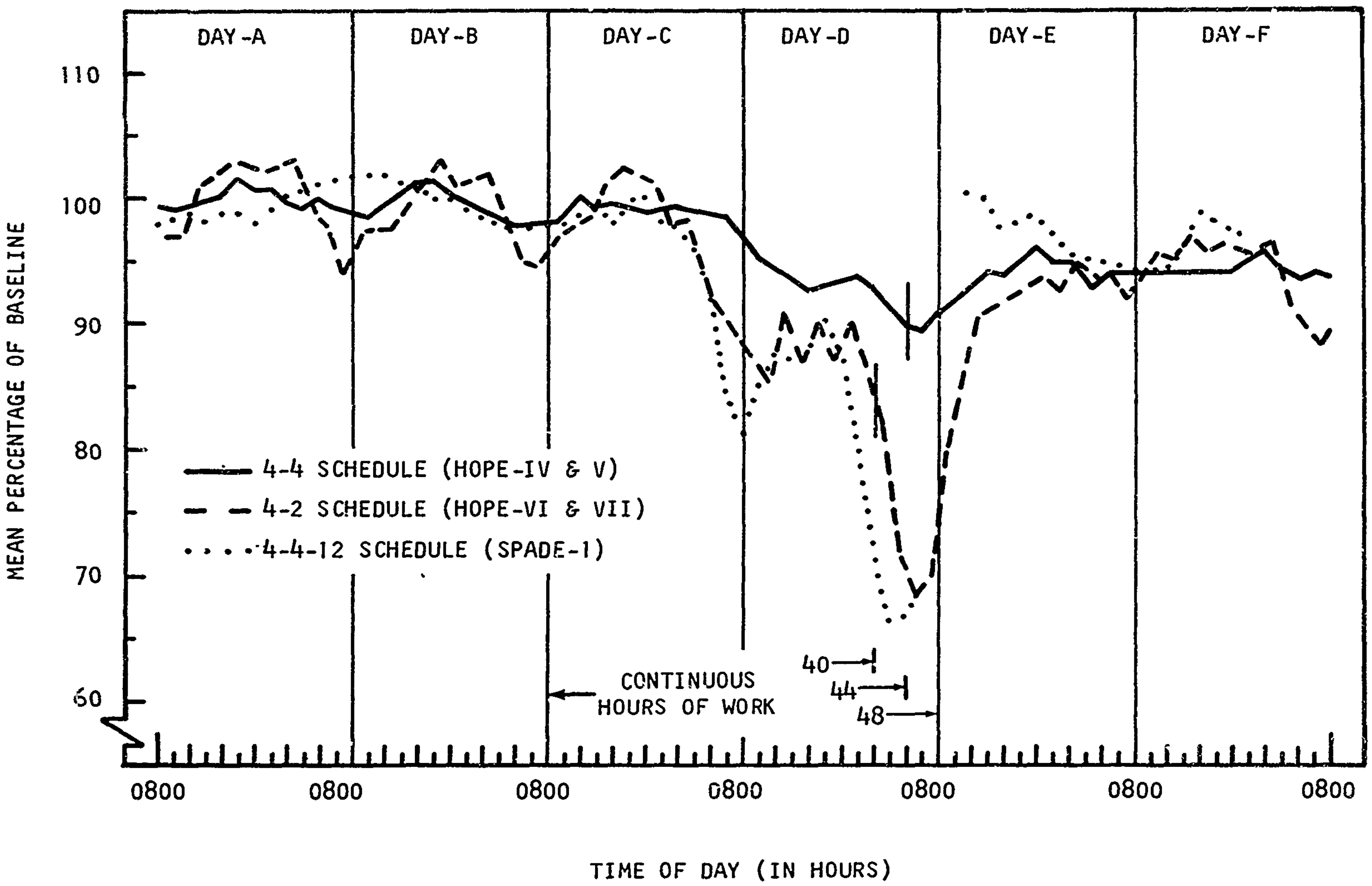


Figure 6.--Mean percentage of baseline performance prior, during, and subsequent to continuous-work or sleep-loss stress for three groups of subjects following different work-rest schedules. Ten subjects worked 8 hours per day on a 4-4-4-12 schedule (SPADE-1), 20 subjects worked 12 hours per day on a 4-4 work-rest schedule (HOPE-IV and -V), and 12 subjects worked 16 hours per day on a 4-2 schedule (HOPE-VI and -VII; data of 6).

represented in Figure 6 as Day C, the subjects on the 4-4 schedule (solid line) went for 44 hours without sleep and those on the 4-2 schedule (broken line) went for 40 hours without sleep. During what would have been their "rest" or "off-duty" periods, these subjects were required to remain awake and work at certain paper-and-pencil tasks; during their "work" or "on-duty" periods they performed their usual work on the tasks of the MTPB. At the end of the sleep-loss periods (44 hours for the solid line, and 40 hours for the broken line), these subjects were permitted to sleep during their "normal" 4-hour (solid line) or 2-hour (broken line) rest periods; they continued to follow their work-rest schedules without interruption of the work segments of those schedules.

The average performance of the subjects on the 12-hour work schedule (solid line) fell only about 10% to 90% of baseline at the end of their 44-hour sleep-loss period, and performance appears to have recovered fairly well to about 96% of baseline by about 2000 hours on Day E after 8 hours of sleep and 8 hours of additional work on the 4-4 schedule. Average performance on Day F and during the 3 days of experimentation that followed that day continued at a stable level between 94% and 99% of baseline. Diurnal cycling was generally not apparent in the performance data of these subjects, except during the period of sleep-loss stress. Even then, the diurnal-cycling effect was relatively small.

The average performance of the subjects on the 16-hour work schedule (broken line) fell about 30% to 70% of baseline, and by 2000 hours on the next day (Day E), after 8 hours of sleep (four 2-hour rest periods), and 12 or 16 hours of work (three or four 4-hour work periods), performance pretty well leveled out at between 93% and 94% of baseline; on Day F and during the 3 subsequent days of the experiment, the average performance of these 12 subjects ranged between 89% and 96% of baseline. In general their average relative performance remained somewhat below that of the other two groups subsequent to the period of sleep-loss stress. Diurnal cycling in the performances of these subjects on the more-demanding 4-2 work-rest schedule was fairly well evidenced throughout, and especially during the sleep-loss period. This shows some of the limitations in the extent to which the physiological rhythm can be overcome.

It may also be noted that the worst performance for both the 4-2 and the 4-4 groups came at the end of the sleep-loss or continuous-work days. Actually, the rolling-mean technique used in plotting the figure gives the impression of a smoother drop in performance than actually occurred with these two groups. In the case of each subject, the very worst performance was obtained <u>after</u> the sleep-loss period had ended; i.e., it occurred during the first duty period following the inadequate 4- or 2-hours sleep of the subjects who had been awake for 44 or 40 hours, respectively. In the case of the SPADE-1 subjects (dotted line) who had been given a 24-hour rest period, the <u>best</u> performance occurred during the first work period after the sleep-loss stress.

This finding has clear implications for work scheduling; namely, if men have endured a stressful period of sleep loss then gone to sleep, one had better not awaken them for duty prior to their having obtained

adequate sleep unless one is prepared to expect very low performance efficiency.

The data of Figure 6 also indicate that the effects of the stresses of sleep loss or continuous work interact with the type of work undertaken during the period of stress and with the previous schedule of activities (or performance reserves still available at the beginning of the period of primary stress). Thus, the subjects on the 4-2 schedule were more-seriously disturbed in their performances than the subjects on the 4-4 schedule (1) in part because the MTP work was apparently harder than a combination of MTP work and paper-and-pencil activities as can be inferred from the differences between the continuous-MTP-work group (dotted line) and the 4-4 work-rest schedule (solid line), and (2) in part because of the performance reserve expended in their meeting the demands of the 4-2 work-rest schedule during the 5 days immediately prior to the beginning of the sleep-loss period.

This latter point is more dramatically made by the data when taken as absolute scores, rather than in the relative scoring of the mean percentage of baseline performance. For example, in Figure 7 the percentages of correct responses in the arithmetic-computations task (when presented without concurrent code-lock solving) are shown for the 4-4 and 4-2 work-rest schedule groups throughout the full 12 days of experimentation by the solid and broken lines, respectively (cf. 6).

Performance before the period of sleep loss was generally inferior on the 4-2 schedule as compared with the 4-4. Also, the subjects on the more-demanding 4-2 schedule were less successful in preventing diurnal cycling in their performances throughout the study, and the cycling was especially noticeable during the period of sleep-loss stress.

## Endurance and Recovery of Performance

In investigating the endurance of man's performance, we have initiated a series of experiments (the SPADE-series; cf. Table 2) designed to measure (a) man's ability to work continuously during extended periods of continuous operations, and (b) the extent to which varying durations of rest and recovery provide for the recovery of performance from the decrements caused by continuous-work and sleep-loss stress. The ultimate goal of this research is to specify not only the limits of man's capabilities with regard to continuous work, but also the range of work-rest schedules that should be considered as viable options in the development of a capability for continuous operations.

In the first of these experiments, SPADE-1, which has been discussed previously, we employed a work-rest schedule that we thought would set the upper limits on both man's endurance (48 hours of continuous work) and the amount of rest and recovery necessary for the recovery of performance (24 hours). It should be noted that a point of consideration followed in the design of this, as well as the other experiments in this series, was that the work-rest schedule should take maximum advantage of both the natural circadian rhythm and the social pattern of activities; i.e., it was decided

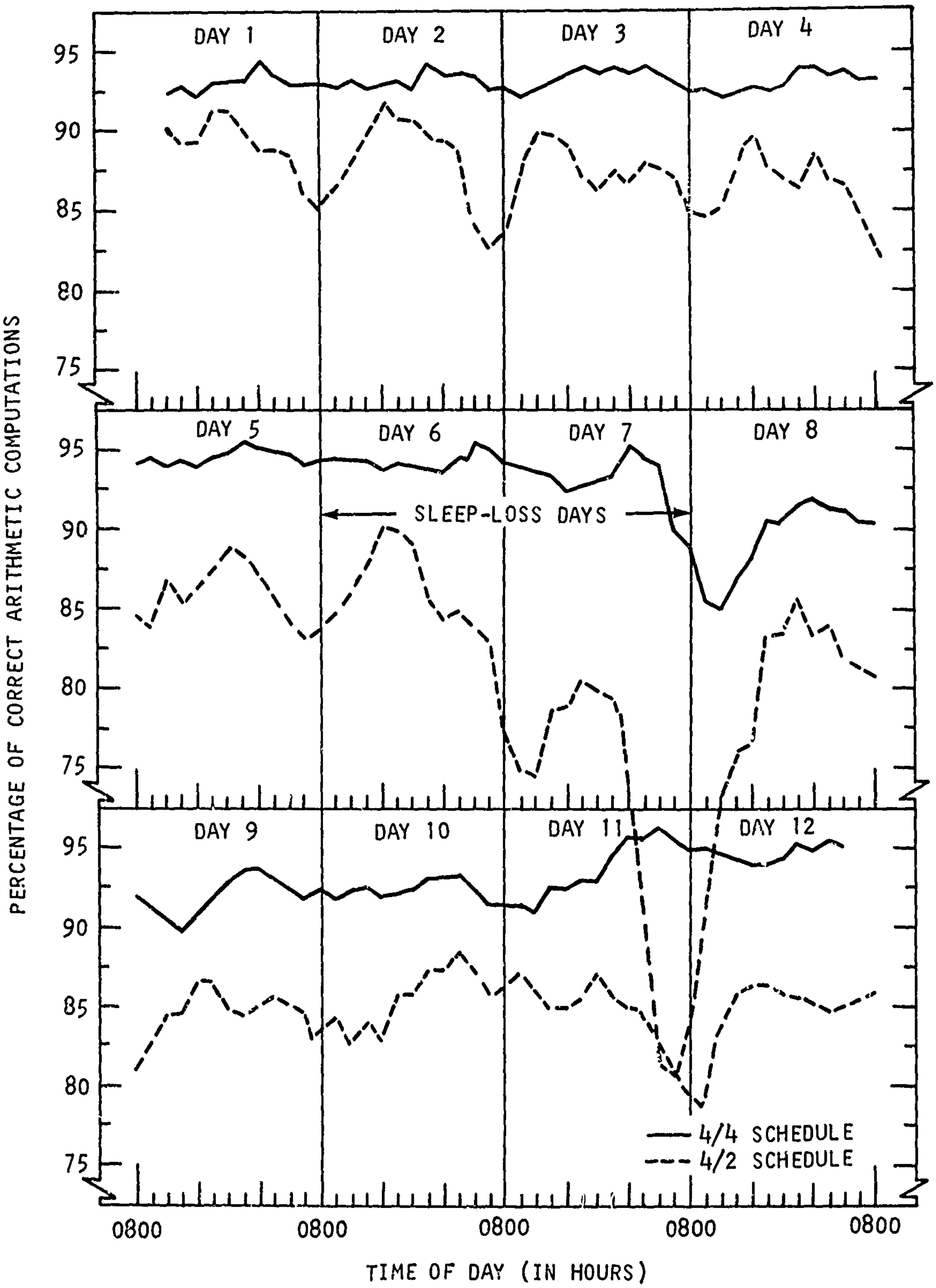


Figure 7.--Average of correct arithmetic computations by 12 subjects on a 4-2 work-rest schedule and 20 on a 4-4 schedule during the 12 days of a sleep-loss study (data of 6).

that the continuous-work/rest cycles should be contained within units of 24, 48, or 72 hours. The results of this first study were presented in Figure 5.

In addition to showing the effects of the circadian rhythm, these results indicate that (a) average crew performance remained essentially unchanged during the first 18 hours of continuous work, (b) a maximum decrement of approximately 34% occurred after about 40 hours of continuous work, and (c) 24 hours of rest and recovery were sufficient to permit the recovery of performance to 100% of baseline. Thus, it appears that man's performance should not suffer in adapting to schedules such as the 10-hours per day, 4-day work week, but that in most work situations man cannot be expected to maintain satisfactory levels of performance continuously for 48 hours. It is also clear that 24 hours of rest and recovery is more than sufficient to provide for the recovery of performance from the effects of continuous work and sleep loss.

Since the major decrements in this study were obtained during the last 12 hours of continuous work, it seemed reasonable to us to expect that subjects might be able to work continuously for 36 hours without experiencing a severe performance decrement, certainly no greater than the 15% decrement that occurred during the first night of SPADE-1. It also seemed reasonable to expect that recovery from 36 hours of continuous work would require substantially less than the 24 hours of rest-and-recovery provided previously, and it is not unlikely that 12 hours would prove to be sufficient. Thus, our second endurance study was designed specifically to assess (a) man's ability to maintain acceptable levels of performance during 36 hours of continuous work, and (b) the extent to which 12 hours of rest-and-recovery following such a work session is sufficient for the recovery of performance to baseline levels.

Thus, in SPADE-2 the 10 trained subjects were required to work 2 days according to the 4-4-4-12 schedule, then work continuously for 36 hours; they were given 12 hours of rest and recovery after which they worked 2 additional days according to the 4-4-4-12 schedule. The results of this study, in terms of the mean percentages of baseline performance, are presented in Figure 8. As can be seen in the figure, these results replicated those of SPADE-1 in three respects: (a) in both studies the first performance decrements began to occur after 18 hours of continuous work, (b) the effects of diurnal cycling were evident in both cases, and (c) complete recovery of performance to 100% of baseline was obtained, even with only 12 hours of rest and recovery. The results of the two studies differed in that a maximum performance decrement of only 11% was obtained in SPADE-2 (as constrasted with a 34% decrement in SPADE-1).

Comparison of the data from SPADE-1 and SPADE-2, as presented in Figure 9, gives some indication of the effects on performance during a period of continuous work of the duration of that work period. The data presented show that the decrement obtained during the 48-hour work period (SPADE-1) was to a point 20% lower than that obtained during the 36-hour period (SPADE-2). The importance of this factor to the planning of continuous operations is quite clear, and additional research should be conducted to

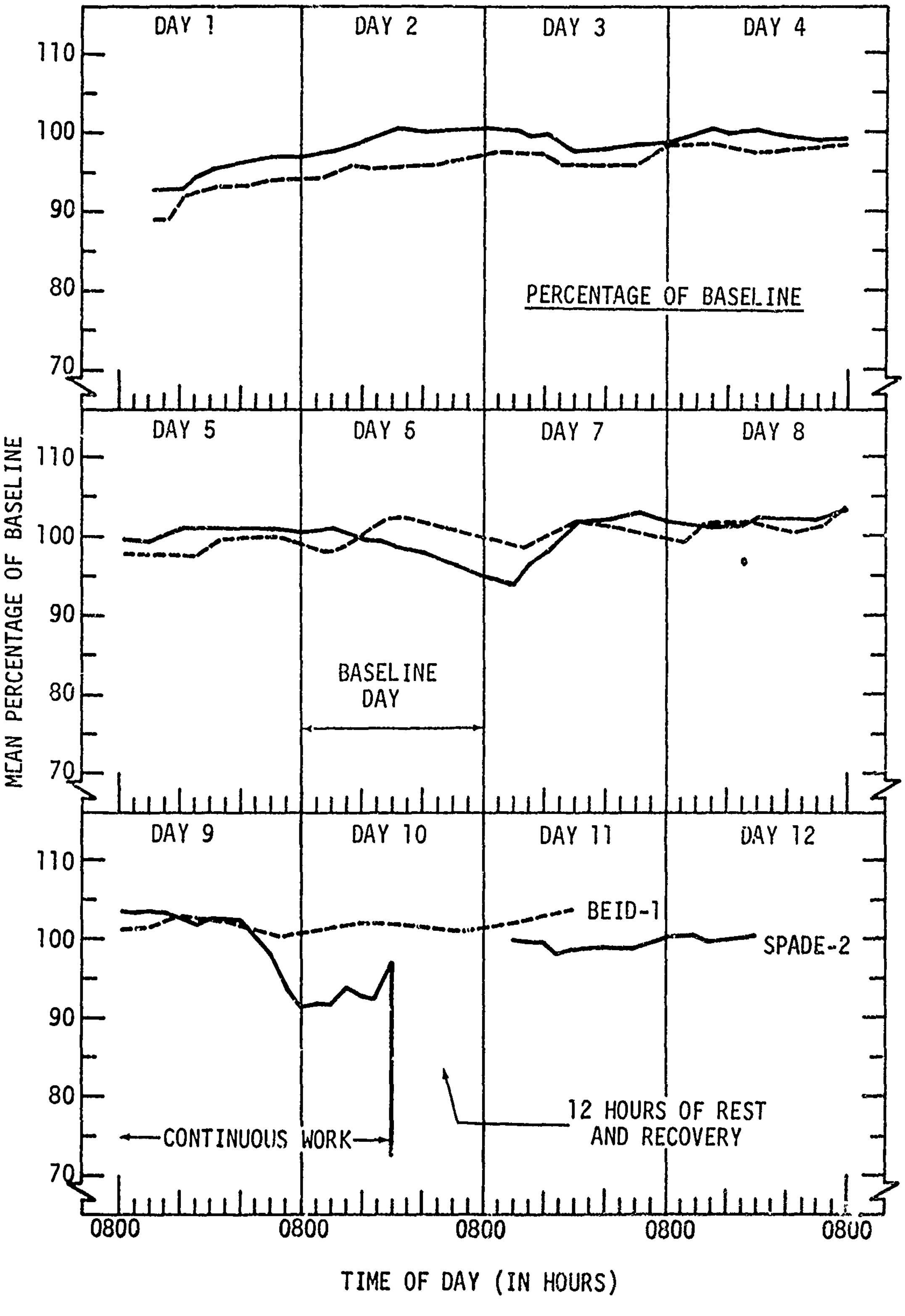


Figure 8.--An index of general performance of the BEID-1 and SPADE-2 subjects: the mean percent.ge of baseline performance.

determine the relation between the percentage of decrement and the duration of the continuous-work and sleep-loss period. Comparison of the data presented in Figure 9 also indicate that essentially equivalent recovery was obtained in SPADE-1 and SPADE-2 following the 24 and 12 hours of recovery, respectfully. Since it was found in the HOPE-series of studies that 2 or 4 hours of sleep was insufficient for (and in fact, damaging to) the recovery of performance, it appears that the minimum amount of sleep needed for recovery lies somewhere between 4 and 12 hours. The next experiment being planned in the SPADE-series will test for this lower limit at 8 hours by giving subjects 8 hours of sleep following 40 hours of continuous work.

It should be briefly mentioned that under current support of a contract monitored by the Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, we have recently completed data collection in a series of studies designed to measure the behavioral effects of interrupted recovery (the BEIR-series; cf. Table 2). The first of these studies (44 hours continuous work/4 hours recovery) was designed to correspond exactly to two of the HOPE studies (HOPE-IV and -V), except that continuous work was employed in the present case. Comparison of these studies will allow inferences to be made concerning the relative stress imposed by 44 hours of continuous and intermittent work (and sleep loss), when the entry into the circadian rhythm is held constant. Comparison of BEIR-2, -3, and -4 (36/2, 36/3, and 36/4) with SPADE-2 (36/12) will allow inferences to be made concerning the relative recovery of performance, from decrements caused by 36 hours of continuous work and sleep loss, provided by 2, 3, 4, and 12 hours of recovery. Extension of these studies could allow us also to determine the relation between the percentage of recovery and the duration of the recovery period, as a function of the duration of the preceding continuous-work and sleep-loss period.

In planning the next phase of our research we will combine the results from the SPADE and the BEIR lines of investigation and will select therefrom our best estimate of the limiting parameters of the most practicable continuous-work/rest schedule. That is to say, the best schedule (probably the 36/12 or 40/8, although the latter will present greater problems in terms of adaptation, organization, and logistical support) will be selected, and this cycle would be tested over a full 30-day period. At the completion of that test we should be in a position to recommend what we consider to be the most workable continuous-work/rest cycle as well as the range of other cycles that might be employed in continuous operations.

## APPLICABILITY OF RESEARCH

The findings discussed above are each relevant to the development of a continuous-operations capability. However, we believe that more important than the specific findings is the programmatic nature of research such as this which serves to reduce the number of experimental options that later must be field tested. In other words, when a mission agency is asked to solve a particular problem--whether related to the development of a portable antitank missile system, determining man's ability to utilize night vision devices, or specifying man's capabilities with regard to continuous-operations requirements--it must provide a solution that is finally field tested, before being considered for full implementation. However, since field experimentation,

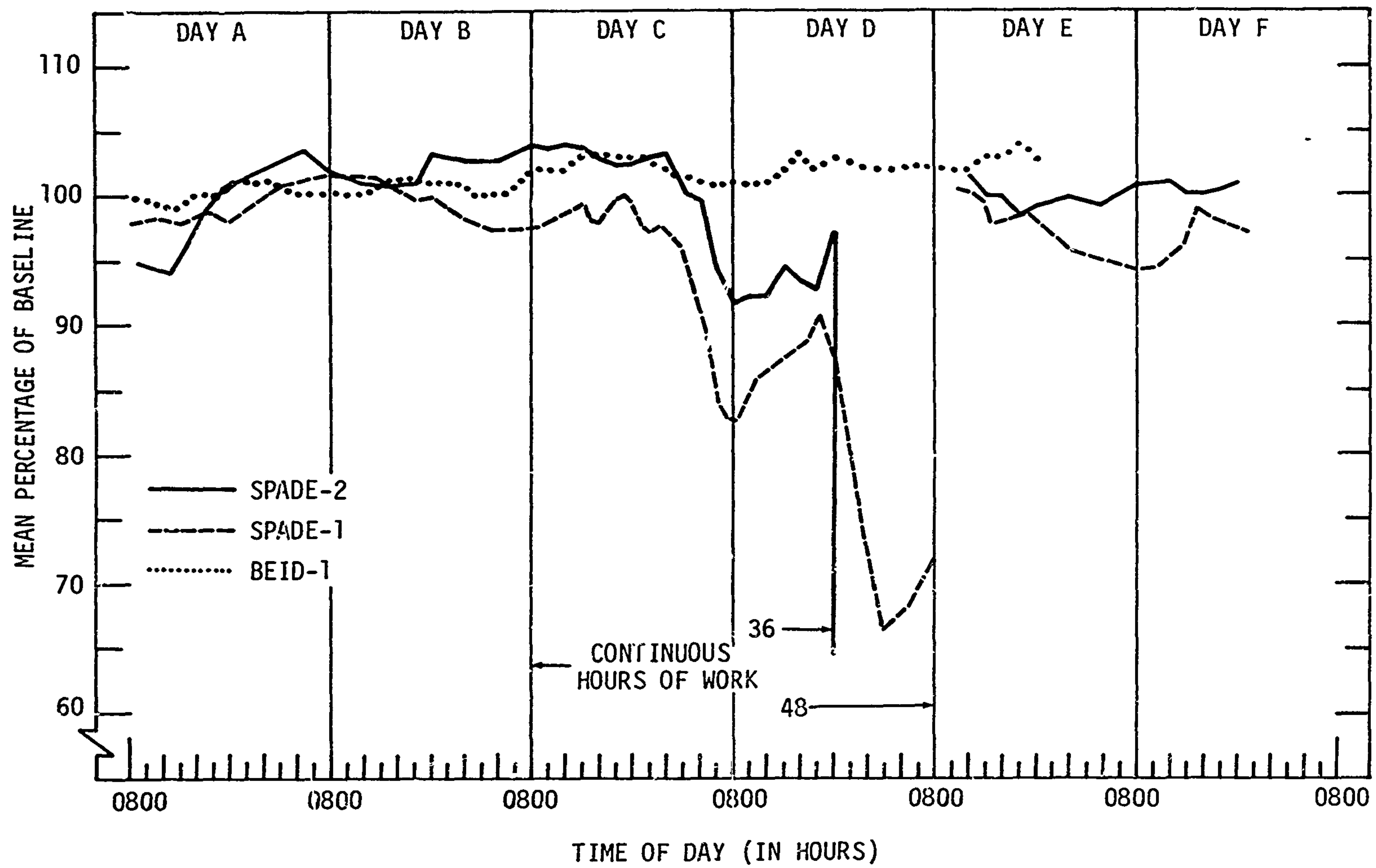


Figure 9.--Mean percentage of baseline performance prior, during, and subsequent to 48 (SPADE-1) and 36 (SPADE-2) hours of continuous work and sleep loss, and during 6 days of a control study (BEID-1).

field manuvers, and usage testing are so prohibitively expensive in terms of time, money, and personnel requirements, the agency must use whatever means available in order to reduce the number and range of the relevant solution parameters, or to select an optimum solution which is then tested in field experimentation. The agency, therefore, is faced with a classical problem of information, or uncertainty, reduction--i.e., it must reduce the number of research alternatives--and in contracting for research the agency is, in essence, buying information (according to its classical definition). The criterion for the purchase of this information should be one of cost-effectiveness. That is to say, the agency should buy (or conduct) research which employs relatively small-scale, inexpensive technical laboratory studies to reduce the range of viable research options; these studies might not necessarily solve the mission problem, but they should guide the agency to a reduced set of alternative solutions whose viability affords that they be tested in the more expensive field studies. We believe that it is in this regard that the research on sustained performance, endurance, and work-rest scheduling is applicable to the development of concepts and doctrine of continuous operations.

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DISCUSSION SESSION

BEN B. MORGAN, JR.

WILLIAM HARRIS: In your 36-hour experiment, will there be continuous performance or will there be some work/rest cycle in the 36-hour period?

BEN B. MORGAN, JR.: There will be continuous work, except to the extent that there are varying work loads within a two-hour period. In 36 hours, the subjects will merely repeat a basic two-hour schedule 18 times, so that there are periods of low performance when they aren't very active. During these periods of low activity we will allow the subjects to go to the restroom, get coffee or cokes, and feed them. But they are on station, working continuously.

LEON KATCHMAR: I'm not sure if I understood your family of curves. Isn't there another aspect that you're concerned with? After extended performance, when you incur a sizeable performance decrement, you recover to a base level in a relatively short period of time, but the rate of decrement after this initial recovery is highly accelerated and performance may go down to zero in a relatively short period of time. You are also going to investigate that, aren't you?

BEN B. MORGAN, JR.: If you permit people inadequate sleep after a period of stress or continuous work, performance will be worse than it was at the end of the continuous work period. This means that when you work a man who has experienced a decrement down to a certain point, and you take off to rest, you had better let him rest long enough. "How long" we don't know yet, but we do know that two hours is not enough for full recovery. You had better let him rest long enough, or he is going to be worse off when he comes back than he was when he left.

LEON KATCHMAR: This is the kind of preditability that we need for military operations. One more point, Ben, is that I like the way you present this for clarity purposes. But, I think it masks all of the variability that you normally see in performance. How much variability is there? Is it rather sizeable as you might expect, or is the variability around your mea curve very small? Not only in the individual differences, but the difference between groups of individuals?

BEN B. MORGAN, JR.: Between groups of individuals we find very little variability: plus or minus five percent of a baseline level of performance. Let's take the math task, for example, so we are talking about absolute scores. The subjects will hit 85 to 95 percent correct, and they will perform within those limits across all of the studies. Individual subjects: I don't

have much feel for that because we don't look at the data in terms of individuals.

# SOME OBSERVATIONS FROM A LITERATURE REVIEW TO ANTICIPATE BIOLOGICAL PROBLEMS THAT MIGHT ARISE IN SUSTAINED AND CONTINUOUS OPERATIONS[1]

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Recently, Dr. William Harris and I reviewed much of the world's literature on sleep deprivation, prolonged physical work and certain additional stresses likely to be encountered by soldiers engaging in sustained and continuous operations ( 2 ). My specific task was to anticipate any physiological dysfunction that might arise in soldiers under those circumstances and to estimate, if possible, the time required for the recovery of normal functioning after periods of sustained military activity.

In the course of that review it quickly became apparent that there exists little directly relevant information for predicting how men will react during sustained and continuous operations. The few field investigations performed on soldiers in combat or in simulated combat provided ambiguous results as a consequence of questionable testing procedures and/or less than adequate controls. Sleep deprivation research provided data which generally were not relevant due to vastly dissimilar task requirements in typical laboratory settings and in prolonged combat operations. Studies on men performing physical work over periods similar to those anticipated for a sustained operation simply have not been conducted. The results from studies on shorter periods of work yielded meager information for predicting problems that might occur in sustained and continuous operations.

Nonetheless, enough information was present in the literature to justify a belief that soldiers will suffer an extraordinary burden of stress in a sustained combat opera-

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tion. Moreover those data suggest numerous potential problems which, taken together, seem to call for a serious re-evaluation of the viability of current concepts of sustained and continuous operations. What follows is therefore a discussion of conclusions from the physiological section of our review. Space does not permit thorough substantiation of each conclusion. For that, the reader is referred to the original document which should be published shortly by the U. S. Army Human Engineering Laboratory, Aberdeen, Maryland.

## BIOLOGICAL EFFECTS OF SLEEP DEPRIVATION WITH RESPECT TO PRESENT CONCEPTS OF SUSTAINED AND CONTINUOUS OPERATIONS

The biological effects of sleep deprivation are poorly understood, as is the biological requirement for sleep itself. Yet it is obvious that some physiological dysfunction must occur during sleep deprivation. Men progressively behave in a more lethargic, erratic, and irrational manner, suggesting progressively deteriorating cerebral function. Also, the fact that animals die after prolonged sleep deprivation seems indisputable proof that some physiological dysfunction has occurred.

Much of the work in this area has concentrated on showing progressive electroencephalographic (EEG) changes that occur in normal individuals who are required to maintain wakefulness over prolonged periods. It is commonly accepted that those changes signify an almost linear decline (up to about 120 hours of wakefulness) in psychophysiological arousal which may affect performance capabilities on certain monotonous tasks, such as monitoring, where high arousal seems prerequisite for efficient performance. However, declining arousal in no way implies cerebral dysfunction and normal arousal is rapidly recovered after one or, at most,

two nights of recovery sleep. In view of the predictable and relatively benign nature of this physiological change, the great effort expended in repeatedly demonstrating the phenomenon seems somewhat misplaced. More important are the changes which signify the development of incipient pathology or those which underlie a performance impairment which is less easily overcome by a compensatory increase in effort.

Physical working capacity, as measured in tests of relatively short duration, is little changed over periods of sleep deprivation of up to five days. However, the ability to perform physical work is apparently retained at some cost. After sleep deprivation is over, a state of reduced physical working capacity persists, to a dimishing degree, for several days. There are some data to suggest that this may be due to an impaired capability for fully utilizing glucose as an energy source.

Body temperature declines during sleep deprivation but it is unclear if this indicates any loss in thermoregulatory capability.

Iron reclamation by the splenic and hepatic reticuloendothelial system is severely and rapidly impaired by lack of sleep. Studies on humans have not found that this results in the pathological condition of hypochromic anemia. However, there is evidence that the erythropoietic system is operating under a high degree of strain to compensate for the reduced availability of iron during sleep deprivation. Any additional strain on the erythropoietic system as imposed by such stresses as physical work, hypoxia, or hemorrhage might result in an inadequate production of mature red cells, and in anemia.

The recovery of the reticuloendothelial system is very slow following sleep deprivation. The effect of 48-72 hours of sleep loss on plasma iron would probably be apparent, in diminishing degree, for as long as a week afterward.

Adrenal functions are affected subtly by sleep deprivation. Little consistent change in adrenal medually secretion of adrenaline occurs, but the sympathoadrenomedullary response in physical work is exaggerated after the loss of only a single night of sleep. During sleep deprivation, the adrenal cortical pattern of cortisol release fails to conform to its usual circadian rhythm--the evidence favors the view that the early-morning rise in cortisol secretion is reduced progressively--beginning after the first night of sleep loss.

Abnormal and possibly pathologic electrocardiogram (ECG) patterns have been observed in healthy individuals after 75 hours without sleep. These changes suggest some myocardial dysfunction which is only slowly reversed by rest after prolonged wakefulness.

Judging from electroencephalographic and neurological evidence, the CNS is the first system to show clear impairment during sleep deprivation and the first system to recover following cessation of that stress. The most obvious cause of that impairment seems to be the decline in the activity of subcortical centers responsible for the general level of psychophysiological arousal.

Pathological signs of epileptic-like cortical activity have been observed in predisposed but otherwise healthy individuals. Thus, it seems that the waning of subcortical control over the cortical level of arousal may accentuate incipient unstable and seizure-related activity within the cortex of certain individuals.

Most individuals show metabolic signs of stress during moderate periods of sleep deprivation. There is evidence of some blocking of carbohydrate metabolism at the point where pyruvic acid enters the tricarboxylic acid cycle. Less secure evidence suggests that this may be due to an induced thiamine (vitamin $B_1$) deficiency. That is, increased thiamine excretion has been found to occur during sleep deprivation. The rate of fat catabolism increases during sleep deprivation, possibly to supply some of the energy lost by the blocking of carbohydrate catabolism in tissues that can use either substrate. In tissues, such as those in the brain, which can utilize only carbohydrates as an energy source, there may be a compensatory increase in the activity of unaffected, though less efficient, metabolic pathways. This has not been observed but may be inferred from studies of erythrocyte metabolism during sleep deprivation. Protein metabolism is relatively unaffected by sleep deprivation. Still, some sleep-deprived individuals show a negative nitrogen balance which indicates a net reduction in the body's protein reserve.

Unfortunately, it is very difficult to generalize strongly from the above findings to the situations that are anticipated in sustained and continuous operations. This is mainly due to the fact that subjects in practically all reported studies on sleep deprivation have engaged in essentially sedentary activities throughout their periods of wakefulness. The energy expenditures required for those activities have presumably been uniformly low. Soldiers engaged in sustained or continuous field operations will not as a rule be sedentary. They will be required to perform physical and "mental" work on an intermittent or continuous basis over long periods. Thus the stress imposed on all physiological systems, save perhaps the CNS, will be far greater than the stress experi-

enced by typical laboratory subjects in sleep deprivation experiments. For example, Goldman (1) has shown that the average rifleman bearing a normal 20 kg load expends energy at a rate of about 3.8 kcal/min while merely marching at 5.5-6.5 km/hr over dry and level ground. More heavily loaded individuals such as radiotelephone operators, mortarmen, and machine gunners expend energy at considerably higher rates while marching; i.e., up to 10 kcal/min. Even riflemen expend energy at high rates (about 7 kcal/min) while engaging in other activities such as a fire fight. Yet it may be estimated on the basis of much related data that the sedentary subject of sleep deprivation experiments does not expend energy at rates much greater than 2 kcal/min. Thus, by the end of 24 hours of continuous activity, the marching and fighting soldier would expend about 5400 and 10,000 kcal, respectively, while the subject would expend only about 2880 kcal.

Applied physiologists have long held that the maximum allowable 24-hour energy expenditure for workers engaged in heavy labor on a daily 8-9 hour basis should not exceed about 4800 kcal. Rates of energy expenditure in excess of that value are thought to be associated with feelings of chronic fatigue and increased susceptibility to physiologic dysfunctions of many kinds. Thus, while subjects of sleep deprivation experiments have not exceeded the "maximal allowable" rate of energy expenditure, soldiers engaged in sustained operations will do so routinely. Consequently, many of the physiological problems observed in subjects during prolonged wakefulness should be exaggerated in soldiers deprived of sleep for similar periods. In addition, it may be anticipated that additional, presently unforeseeable, problems will occur in the latter group as they endure the combination of many stresses, including sleep deprivation.

## SOME EFFECTS OF PROLONGED PHYSICAL WORK WITH RESPECT TO PRESENT CONCEPTS OF SUSTAINED AND CONTINUOUS OPERATIONS

From what's been said previously one might assume that research on the psychological and biological effects of prolonged physical work would have more to offer for predicting how men will react in a sustained military operation. Unfortunately this is not the case. There has been no report of any investigation in which men have performed under a constant work load for periods exceeding 24 hours. (In the one study where men were *asked* to work under a moderate load for 24 hours only a few [9 of 47] were able to actually complete the task [3]!) The psychological effects of prolonged physical work have been, generally, either ignored or noted in a cursory manner. Moreover almost no one has bothered to measure the recovery of individuals who have worked for prolonged periods.

Yet much is known about the limiting factors for performing physical work and some of that information was useful for our purposes. Before discussing this, however, a brief description of procedures commonly used for assessing physical working capacity should be given.

It is well known that oxygen consumption, $\dot{V}_{O_2}$, increases as a linear function of increasing work load to the point where the cardiorespiratory system becomes incapable of providing additional oxygen to the working skeletal muscles. The measurement of the maximum rate of oxygen consumption, $\dot{V}_{O_2max}$, is taken as an index of an individual's maximum aerobic working capacity. Typically, $\dot{V}_{O_2max}$ is determined in brief (<30-minute) tests requiring the individual to work on a treadmill or a bicycle ergometer under a steadily increasing load until he can no longer continue. After noting

a subject's terminal work load, investigators often subsequently study the same subject as he works under a load which causes his $\dot{V}_{O_2}$ to stabilize at some particular percentage of $\dot{V}_{O_2max}$. He is then said to be performing at that percentage of his maximum capacity, or submaximally.

It is generally accepted that no individual can perform near his maximum capacity for more than several minutes. Naturally, individuals can perform physical work for increasingly longer periods at progressively lower work loads.

Generally, it is conceded that well trained men can perform under the same work loads for considerably longer periods than healthy but untrained individuals of the same ages. According to most authorities, highly trained individuals can be expected to work continuously at 50% of their maxima for a period of eight hours, whereas untrained individuals cannot be expected to work at much more than 25% of their maxima over the same period.

Generally speaking, estimations of the times men can be expected to work under different work loads based on laboratory experiments have been supported by observations of the energy expenditures of various occupational groups. For the average healthy young male (body weight 70 kg), with a normal diet and a $\dot{V}_{O_2max}$ of 3.5L, the rate of energy expenditure associated with physical work at 50% and 25% of relative maximum is approximately 9 and 5 kcal/min, respectively. In studies of the energy expenditures of various occupational groups, it has been shown that the average eight-hour working day rate of energy expenditure rarely exceeds 6 kcal/min, even in occupations involving manual labor. Occasionally, however, many individuals in lumbering, mining, and building occupations have been shown to sustain bursts of activity associated with rates of energy expenditure which are up to

twice that value. Consequently, it may be said that well-trained men engaged in occupations that require intermittent or continuous heavy physical labor typically work at between 30% and 40% of their maximum capacity, with occasional periods of working at one-half of their maximum capacity, or more, without incurring the need for unusually long periods of recuperation.

But soldiers engaging in a sustained operation will often be expected to perform physical work for periods considerably longer than eight hours. Thus, the literature on prolonged physical work cannot be used for stipulating how long men might be expected to perform efficiently in a sustained operation or how long it will take for their subsequent recovery. It does provide some idea of what factors may limit their endurance. It is generally accepted that the factor limiting work under near maximal loads is an insufficient blood flow for providing oxygen to the working muscles and removing accumulated $CO_2$, lactic acid, and heat from them. It also appears that the depletion of carbohydrate energy sources at the skeletal musculature and, possibly, at the CNS, limits work performed under heavy, though submaximal work loads. Under work loads greater than about 70% of maximum, the limiting factor presently appears to be the depletion of muscle glycogen depots. However, at work loads between 50% and 70%, the limiting factor may be the same and/or an exhaustion of liver glycogen causing the circulating concentration of glucose to fall below the level required for the maintenance of normal CNS function.

The best available evidence suggests that work under more moderate loads (i.e., between 33% and 50% of maximum), such as those experienced by riflemen carrying full packs and marching at 6.5 km/hr, is likely to be limited by progressive dehydration.

A digression to examine the problem of dehydration might be informative at this point. It is well known that the mechanism of thirst is not sufficient for maintaining fluid balance in exercising men, particularly in hot (> 28C) environments. After losing water due to perspiration and increased respiration, men do not immediately replace the lost fluid by drinking when unlimited water is available. Rather, the water is replaced gradually over hours or days, even though this slow return to fluid balance may leave the individual behaviorally and physiologically debilitated during the interim. This phenomenon has been widely recognized and has been called "voluntary dehydration," or more correctly, "involuntary hypohydration."

The body water loss during prolonged submaximal work may be substantial: water deficits up to 8% of initial body weight have been frequently reported. The physiological effects of hypohydration are varied and may be severe. After as little as a 1%-2% water loss, there is clear indication of increased circulatory strain; i.e., with a diminished plasma volume, the heart must beat more frequently to maintain a constant cardiac output. A progressive water deficit also leads to declining capability of the thermoregulatory system for maintaining body temperature. The sweat rate falls, leading to rising body temperature and further decline in sweat rate. If left unchecked, progressive dehydration would certainly lead to circulatory insufficiency, heat exhaustion, or both.

Psychologically, hypohydration increases subjective feelings of fatigue. Naturally enough, this decreases motivation for performing physical work. A remarkable example of how extreme that reaction can be may be taken from Strydom *et al.* (4). Those investigators studied the reactions of 60 soldiers carrying 24 kg and marching at 6.5 km/hr on a 29 km hike. Throughout the march, the ambient temperature

and humidity were moderate. Half of the group was allowed one liter of water while the other half was permitted to drink *ad lib.* (the latter, in fact, drank an average of 2.7L during the march).

Seven of the water-restricted soldiers and one from the *ad lib.* group fell out or collapsed in exhaustion. Those from the water-restricted group who completed the march endured an average 4.8% (of body weight) water loss, and a 1.7C increase in body temperature. Those from the *ad lib.* group who were successful endured an average 3.9% water loss and a 1.2C increase in body temperature. Thus, both groups became hypohydrated and suffered from hyperthermia, although to different degrees. More striking were the effects of hypohydration on the men's morale. According to the authors:

> At the start, and even up to about the third hour of marching, there was little to distinguish between the two groups with respect to general appearance and behavior. Thereafter a distinct difference in reaction and appearance occurred. Whereas the morale of the *ad lib.* group remained high throughout, that of the restricted group was markedly poor; they became morose, aggressive, and disobedient towards their superiors and showed obvious signs of fatigue. A subject from [the restricted] group defied all orders and attempted to snatch water from a subject in the other group. One of the unsuccessful subjects complained bitterly to the officer-in-charge when refused additional water and then summarily refused to walk further. He was given extra water, allowed to ride on the truck and then became most apologetic about his behavior.
>
> The response to discipline among the group decreased markedly towards the latter part of the march. The members of [the restricted] group were mainly responsible for this decline. On being reprimanded for not keeping up the pace, they talked back and were difficult to control. To some extent, this behavior also influenced men in the [*ad lib.*] group, but in general these men were still easy to handle and kept their positions in order of marching until the end.

The authors could not deny the possibility that the low morale in the water-restricted group partly resulted from feelings that they had been unfairly selected for an exceptionally stressful experience. Nonetheless, the striking and unusual degree of insubordination shown by the men to their officers strongly suggested that hypohydration had the effect of dramatically reducing the men's tolerance for frustration while increasing their feelings of fatigue.

Recovery from hypohydration is relatively slow. For example, restoration of fluid balance after severe (6%-8%) hypohydration requires 2-3 days for completion.

The problem of involuntary hypohydration may be precluded in sustained and continuous operations by determining water and electrolyte balance at frequent intervals and by forcing replacement of lost water and salt. In view of the likelihood and seriousness of the problem, this measure seems mandatory.

## CONCLUDING REMARKS

In addition to the consequences of sleep deprivation and prolonged physical work, it is likely that men in sustained and continuous operations will suffer from the disruption of certain of their biological rhythms, from the threat of injury and/or death, and from environmental stressors such as heat or cold.

Physiological dysfunctions that might occur in men operating according to unusually long work/rest cycles are matters for conjecture. This is mainly because no one understands the nature of, or necessity for, circadian periodicity in biological functioning. Nonetheless, there are a few research findings which indicate that certain biological rhythms may be essential for the maintenance of homeostasis and behavioral efficiency. Other findings suggest that the

disruption or attenuation of certain biological rhythms may lead to increased sensitivity to some disease states and reduced tolerance for various environmental stressors. Yet, there is no evidence which *directly* indicates that these phenomena will occur in soldiers who no longer fight during the day and rest during the night. Still, these distinct possibilities cannot be ignored.

Exposure to combat produces a state of stress which is in many ways more severe and persistent than those produced in laboratory studies on sleep deprivation or prolonged physical work. Work completed during the Korean War has shown that infantrymen, exposed for less than a day of intense combat, lose nitrogen in a manner suggesting a marked increase in protein catabolism. Soldiers exposed to less intense combat for longer periods were found to become hypohydrated and showed hematological changes suggesting some impairment of the body's defenses against infection. Whether their exposure was long or short, infantrymen apparently developed diminished adrenocortical and sympathoadrenomedullary responsiveness as a result of combat experience. That is, their ability to rise physiologically to meet new challenges appeared diminished. Recoveries from these states of stress were slow, requiring at least five days, and usually longer.

More recent data have shown that the effects of combat stress may be greater in infantrymen who, by means of rank or specialty, possess greater awareness or responsibility in the stressful situation. Furthermore, the finding of slowly reversible alterations of lipid metabolism in naval aviators flying combat missions clearly demonstrates the potency of threat as a stressor in combat. Those men were properly nourished and their rest between missions was at least sufficient to ensure a high level of performance efficiency. They were not subject to heavy physical work or extreme environmental conditions. Yet their physiological homeostasis

was disturbed in a manner that might eventually lead to the failure of a susceptible physiological system.

Men engaging in sustained or continuous operations will rarely perform their missions under optimal environmental conditions. It is predictable that they will often be required to endure thermal stress. If those missions are conducted at altitude, they will operate under hypoxic stress. Armored personnel will have to endure additional stress resulting from confinement, noise, and vibration. Given the high caloric requirement of troops, and the difficulty of fulfilling that requirement during sustained and continuous operations, it is even possible that those personnel will suffer a nutritional deficit. All of these factors have been repeatedly shown to impair physical and mental working capacity and to increase susceptibility to diseases of many types. Thus any attempt to generalize from the information provided in this summary of research findings should be tempered with the knowledge that the information was compiled largely from studies in which the isolated effects of a stressor, such as sleep deprivation or physical work, was studied under otherwise benign circumstances. Under realistic field conditions, it can be expected that the degradation in both the men's performance and physiological status will occur much more rapidly and recovery will be slower as a consequence of the combination and interaction of the effects of numerous stressors.

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## DISCUSSION SESSION

James F. O'Hanlon

<u>NANCY BETHEA</u>: In designing research to show how individuals react in a sustained operation, what physiological measurements would you use.

<u>JAMES O'HANLON</u>: A number. Shall I go down the list?

<u>NANCY BETHEA</u>: Yes.

<u>JAMES O'HANLON</u>: Well, it definitely depends upon one's resources. For answering your question, I'll assume that those resources are unlimited.

I would definitely measure water volumes in the body's three water compartments; that is, the plasma, the extracellular fluid, and intracellular fluid. I would measure muscle glycogen and blood glucose levels. Measurements of plasma concentrations and urinary excretion rates of the major stress hormones; adrenaline, noradrenaline, plasma cortisol or its excreted metabolites, the 17-hydroxycorticosteriods, also seem justified.

Recently there have been demonstrations of circadian periodicities for plasma levels of insulin and growth hormone. Those agents are responsible for restoring depleted energy reserves and their circulatory levels are generally highest at night. It is possible that their levels might not fluctuate in a manner to restore the depleted energy reserves in soldiers engaging in a sustained operation. I would include measurements of insulin and growth hormone to determine whether that is the case.

Among physiological variables, I would definitely measure indices of cardiovascular function during work, rather than during rest, as has been done in the past. Those indices should certainly include cardiac output under a constant work load. Also, measurements of orthostatic tolerance, obtained in the usual manner, might yield an interesting picture of an altered ability for maintaining blood pressure during a sustained operation.

Measurements of submaximal working efficiency, or cost, might also be illuminating--but only if those measurements are taken in tests of extended duration. I think it's been shown often enough that short, circumscribed tests of maximal working capacity or submaximal working efficiency often reveal little of the obvious deterioration in the stressed individual's physiological status.

Of all measurements, those which indicate the functional efficiency of the iron reclamation and erythropoeitic system might be the most revealing. Sleep deprivation impairs iron

reclamation and apparently strains the erythropoeitic system's capacity for producing red blood cells. Further strain as imposed by increased red blood cell destruction in prolonged physical work or by blood loss due to hemorrhage might lead to that system's failure. Hypochromic anemia would then result.

I believe I've listed enough measurements to keep a team of researchers busy for a long time. Should I stop here?

LEON KATCHMAR: You would like to measure everything, wouldn't you?

JAMES O'HANLON: With unlimited resources, I certainly would.

# PHYSIOLOGICAL RESPONSE TO PROLONGED MUSCULAR ACTIVITY[1]

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## INTRODUCTION

Muscular work in industrial, military, as well as recreational activity is seldom maintained at a steady state for long periods of time. Therefore, a steady state as discussed in the literature is seldom achieved except when the activity is regulated. Although the laboratory studies where subjects are continuously working for periods of time on a treadmill or a bicycle ergometer represent artificial situations, such studies have certain advantages. These advantages are apparent when studying physiological responses to exercise or when studying certain types of patients, for they provide certain standardized conditions that will permit comparisons. Laboratory studies also may simulate different types of levels of work or demand on the body in many work-rest schedules. Although continuous studies have been stressed, the study of the effect of intermittent work is very important for it simulates how man actually carried out an activity; the response of body functions to the severity of the activity. In a study by I. Astrand et. al, 1960 (a, b) they found that under a heavy load of exercise exceeding subject's maximum aerobic capacity the subject has been able to perform for only 8 minutes. On the other hand under similar loading, when the subject alternated between 3 minutes of work and 3 minutes

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of rest, he was able to proceed although with difficulty for approximately one hour for same amount of work. When the heavy work period was shortened by introducing rest periods more frequently, the total oxygen uptake over the hour was not markedly reduced, but the subjective feeling of strain was less severe. With intermittent work and rest the increase in the rest period apparently results in prolonged activity and the delay of the onset of fatigue.

Fatigue, generally defined as the transient loss of work capacity resulting from preceding work, is one of the complex biological problems that the exercise physiologists are faced with, for it limits performance in both the normal as well as the pathological condition. It produces the feeling of discomfort, frustration and interferes with one's well-being.

Recovery, opposite of fatigue, can also be used as criterion of fatigue. The speed of recovery is a determinant for the frequency and duration of rest pauses in order to maintain prolonged performance and therefore has important applications. Recovery here is defined as the return of any elevated metabolic and/or cardiovascular functions to the resting stage at the end or after the termination of the work. If a steady state for metabolic respiratory and cardiovascular functions is reached in prolonged performance, it may indicate that there is an equilibrium between the catabolic and anabolic processes. If however, the work load is greater than can be compensated for by simultaneous recovery processes, then it is impossible to achieve a steady state. Instead, metabolities and other physiochemical changes accumulate and hence lead to fatiuge. It has been indicated by Simonson (1971) that a true steady state does not exist. In fact, during prolonged muscular work at a steady state of oxygen up-take ($V\ O_2$), there is a continuing depletion of energy generating reserves. In addition, a steady state of $V\ O_2$ may not necessarily be paralleled by steady states of respiration, pulse rate or even

oxygen debt. Therefore, recovery as a function of time during or immediately after work determines a relationship between the intensity of the work load and endurance. Monod and Scherrer (1957) have demonstrated that this relationship between intensity of work and endurance appears to be a fundamental characteristic of performance. It should be noted, however, that recovery during work is much more important than recovery after work especially in prolonged activities, but due to the difficulty of measuring and determining recovery during work, most investigations were concentrated on recovery after termination of work.

Prolonged Muscular Work

During prolonged activities metabolities and other physio-chemical changes accumulate, its rate of accumulation is dependent on the intensity of the activity. The slower recovery after prolonged and/or strenuous work is due to this accumulation. Astrand (1960b) reported that subjects performing at 50% of their aerobic capacity could work for one hour without fatigue at a steady state. He also reported that activity for 8 hours with 10 minute rest pauses every hour with one hour for lunch can be carried out at steady state of oxygen, RQ, lactate, and rectal temperature. But an increase in heart rate and decrease in body weight coupled with a feeling of discomfort towards the end of the work day was observed. Based on the experiments by Michael, Hutton, and Horvath (1961), they reported that for continuous work on a bicycle or treadmill walking for 8 hours without interruption, 35% of macimum aerobic capacity is the limit of work that can be performed without fatigue. Work at 50% of maximum aerobic capacity appears to be the upper limit of work tolerance for 8 hours attainable only by a select group. Passmore, Passmore and Durnin (1955) also proposed a limit of energy expenditure to be approximately 5 Calories per minute or about 1 liter of $O_2$ which is approximately 30% of maximum aerobic capacity. There appears to be a considerable amount of work which leads to the

level of loading as a percent of aerobic capacity under which an individual can work for an extended period of time without undue fatigue. Lehmann (1962) proposed maximum limits for muscular work from one minute to one year. His values appear to be in agreement with those reported by Passmore, Passmore and Durnin reported above.

Whenever man is expected to perform for long periods of time, rest pauses become an effective tool in prolonging the activity without undue fatigue. Intermittent pauses are the most effective way of maintaining or increasing work performance. Although considerable work has been reported on the effect of pauses, whether these may be micropauses or long pauses, it appears that more work is needed to investigate the effects of these pauses during prolonged activities lasting more than 16, 24, or 48 hours of continuous work. Work has been done in investigation of short pauses, for example, the work by Muller and Karrasch (1955) showed that accumulative effects appear in work schedules of 5 minutes of work and 5 minutes of rest alternately. Accumulative effects were also observed when the work/rest schedule was changed to 2 minutes of work and 3 minutes of rest alternately. On the other hand when the work/rest schedule was made of 0.5 minute of work and 0.75 minutes of rest alternately, no accumulative effects were observed. Other investigations of work/rest effects on physiological functions were also reported by Astrand (1960a) which are in the same line as those reported by Muller and Karrasch. In another study by Astrand, et. al (1960a) he showed the favorable effects of intermittent work was due to the brevity of work periods rather than that of rest pauses and therefore it was suggested that this is due to better utilization and replenishing of oxygen stored in myoglobin. As for long pauses that last from 5 to 30 minutes in occupational work the literature is quite large. Such literature can be found in the monographs of Lehmann (1962), Bartley and Chute (1947), and Schmitke (1965).

In general, the effect of rest pauses in work is favorable especially for short pauses than for prolonged pauses, Simonson (1971).

In discussing rest pauses, one must mention some of the physiological mechanisms and their reaction to these pauses. It appears than during rest pauses the greater part of oxygen debt is removed in the first minutes of recovery because of the nature of the recovery function being an exponential one. Another fundamental process is the loss of adaptation toward work during the pause. Simonson and Hedestreit (1930) have demonstrated this phenomenon.

Another type of pauses, called active pauses, is reported in the literature. Sechenov (1901) first discovered its favorable effects. Active pauses refer to periods of time where the activity is shifted from one part of the musculature to another or the work is reduced in intensity. Ricci et. al (1965) compared $VO_2$, VE, $VEO_2$, and heart rate after a 3 minute treadmill exercise in standing position and during a walk on the treadmill at a moderate speed for a recovery period of ten minutes. In the light of the parameters studied, stand recovery was as effective as walk recovery. The walk recovery was subjectively preferred.

## PURPOSE

The ultimate objective of this program of studies it to evaluate the ability of man to:

1. Work for an extended period of time without a level of fatigue which would cause him to terminate the activity.
2. Assess the oxygen consumption build-up as the activity progresses in time.
3. Evaluate recovery patterns when man works on alternating levels of load, one of which is medium level of work (6.25 K cal/min.) and second is low level of work (3.75 K cal/min.).

4. Evaluate the ability of man to perform physical work over a 24 hour period continuously with regular rest periods.

5. Study the relation between human circadian rhythms and physical performance.

## PROCEDURE

In order to carry out the objectives discussed in the section on Purpose above, several experiments were carried out during the last year. These may be divided into three basic phases:

1. Experimentations to study the effects of alternating physical work.

2. Effect of 8 and 16 hours of work on man.

3. The effects of continuous 24 hour physical work with regular rest periods.

### Alternating Physical Loading Studies

In the alternating physical loading studies subjects performed muscular work by running on a treadmill. To simulate the alternate loadings the subjects were required to run for one full hour, but alternate every 5 minutes between a medium load (6.25 K cal/min.) and a low load of 3.75 K cal/min. Prior to running on the treadmill each subject was measured for oxygen consumption and heart rate at rest. This was done for approximately 10 minutes after which he was asked to perform the activity on the treadmill for a period of the 60 minutes in this case and then at the end of the one hour he was permitted to recover for a period of 20 minutes. During the period of activity and recovery, oxygen consumption and heart rate were monitored continuously. The subject was required to start the physical loading work at the medium load after which the load alternated between medium and low every 5 minutes.

Similarly additional alternate loading studies were performed on a 5-5 minute alternating loading basis for two and three hours respectively. For the two hour work activity the subject was permitted to rest for 10 minutes prior to the activity during which oxygen consumption and heart rate were monitored, after which he performed the activity on the treadmill for 2 or 3 hour periods in an alternate load (medium and low) every 5 minutes respectively. After completion of work, a period of 20 minutes of recovery was permitted. During the activity and recovery periods, oxygen consumption and heart rate were also monitored continuously.

Other versions of the alternate loading study were conducted in which the alternating loads were maintained at medium and low. However, the period of loading was changed to 10-10, and 15-5. This means that in one study, subjects performed the activity on the treadmill at 10 minutes for the medium low shifting downwards to the low load for 10 minutes and the activity is repeated alternately on the 10-10 basis. In the second study the subjects performed the medium load for 15 minutes and then shifted to the low load for 5 minutes. These studies were also conducted for one hour, two hour and three hour activity periods. Oxygen consumption and heart rate were also monitored continuously during the activity and recovery periods.

Eight and Sixteen Hour Experimentation

During this experimentation the subjects performed a muscular loading task and a psychomotor task alternately, each being performed in a block of two hours. The physical loading task is identical with the alternate 5-5 loading task described above. After the one hour loading on the treadmill, the subject was permitted to rest for approximately 20 minutes. During the loading period as well as the resting period, the subject was monitored for oxygen consumption and heart rate continuously. This work arrangement for physical loading and psychomotor task was carried out for a period of eight hours. A similar experiment was performed using the same schedule for 16 hours. Each of these 8

hour and 16 hour experiments were maintained for one week each. A total of 4 subjects participated in these experiments. Each subject performed on both the 8 and 16 hour experimentation.

The 24 Hour Experimentation

For this investigation the subject was required to perform a physical loading task at a level of 30 and 50 percent of the subject's aerobic capacity. The physical loading task was maintained for a 24 hour duration with regular rest periods. The work-rest schedule was such that each subject ran on the treadmill for one hour out of each two. Therefore, the subject would run for one hour on the treadmill and have a recovery period of one half hour after which he was allowed 15 minutes for personal needs. Immediately after that he would be readied for the following one hour run. Subjects were required to have one meal every 4 hours. Table 1 shows the routine arrangement. Each subject ran the two levels of 30% and 50% of their work capacity in the same manner staring with the 30% aerobic capacity and was given a week period before runing the 50% aerobic capacity run. Therefore, any effects of fatigue after the first run would not affect the performance on the second run. During resting, working, and recovering the subject was monitored for oxygen consumption and heart rate as well as rectal temperature continuously.

Physiological Rhythms

During the 8-16 and the 24 hours experimentation, additional measurements were taken to investigate possible relationships between physiological rhythms and performance. Before and during the experiments each subject regularly monitored his oral temperature, his heart rate, and obtained a urine specimen. These measurements also were taken during a tracking experiment and during a separate 5-5 treadmill task.

## RESULTS AND CONCLUSIONS

The results of these series of projects will be summarized in four sections:

Table 1. 24 Hours Continous Work Schedule

| FROM | TO | DESCRIPTION |
| --- | --- | --- |
| 8:00 a.m. | 10:00 a.m. | Work Period #1 |
| 10:00 a.m. | 12:00 a.m. | Work Period #2 |
| 12:00 Noon | 1:00 p.m. | Lunch |
| 1:00 p.m. | 3:00 p.m. | Work Period #3 |
| 3:00 p.m. | 5:00 p.m. | Work Period #4 |
| 5:00 p.m. | 6:00 p.m. | Dinner |
| 6:00 p.m. | 8:00 p.m. | Work Period #5 |
| 8:00 p.m. | 10:00 p.m. | Work Period #6 |
| 10:00 p.m. | 11:00 p.m. | Break--Supper |
| 11:00 p.m. | 1:00 a.m. | Work Period #7 |
| 1:00 a.m. | 3:00 a.m. | Work Period #8 |
| 3:00 a.m. | 4:00 a.m. | Break--Snack |
| 4:00 a.m. | 6:00 a.m. | Work Period #9 |
| 6:00 a.m. | 8:00 a.m. | Work Period #10 |

Schedule for the 2 Hour Work Block

| TIME | DESCRIPTION |
| --- | --- |
| 00:00 | Urine Sample |
| 0:00-0:15 | Rest--monitor hour and $O_2$ uptake at the end grip strength |
| 0:15-1:15 | Walk on treadmill--monitor hour and $O_2$ |
| 1:15-1:45 | Recovery--take grip strength at the start--monitor hour and $O_2$ |
| 1:45 | Urine Sample |
| 1:45-2:00 | Free Time |

1. The alternating loading studies,
2. The 8 and 16 hour loading study,
3. The 24 hour loading study,
4. Physiological rhythms and performance.

The alternating loading studies:

A. The 5-5 physical loading studies: The results of the 5-5 loading studies indicate that the food intake and the time of food intake may significantly affect the performance. For example, Figure 1 shows the relationship of four different diets given to the subjects immediately prior to performance.

These diets were:

1. The 23% diet in which 23% of the daily caloric intake of the subject was given prior to the physical loading run.
2. The 7 + 15% diet in which 7% of the daily caloric intake of the subject was given prior to the run and 15% was given immediately afterwards.
3. The 38% diet in which 38% of the total daily caloric intake of the subject was given prior to run.
4. The 23 + 15% diet in which 23% of the daily caloric intake was given to the subject prior to the run and 15% was given immediately upon completion of the run.

Inspection of Figure 1 indicates that two specific diets (23% and 23 + 15%) seem to show the smallest amount of oxygen consumption for the subjects for both the medium level work and the low level work. However, it must be noticed that the relationship seems to shift to the right as the subject goes from the high load to the low load. For example, the 7 + 15% diet gave the highest oxygen consumption for the high load as compared to 38% which gave the highest oxygen consumption for the low load. The same results are also shown for heart rate. Figure 2 shows the effect of diet on heart rate in beats per minute. Again it is clear that the two diets, 23% diet as well as the 23 + 15%

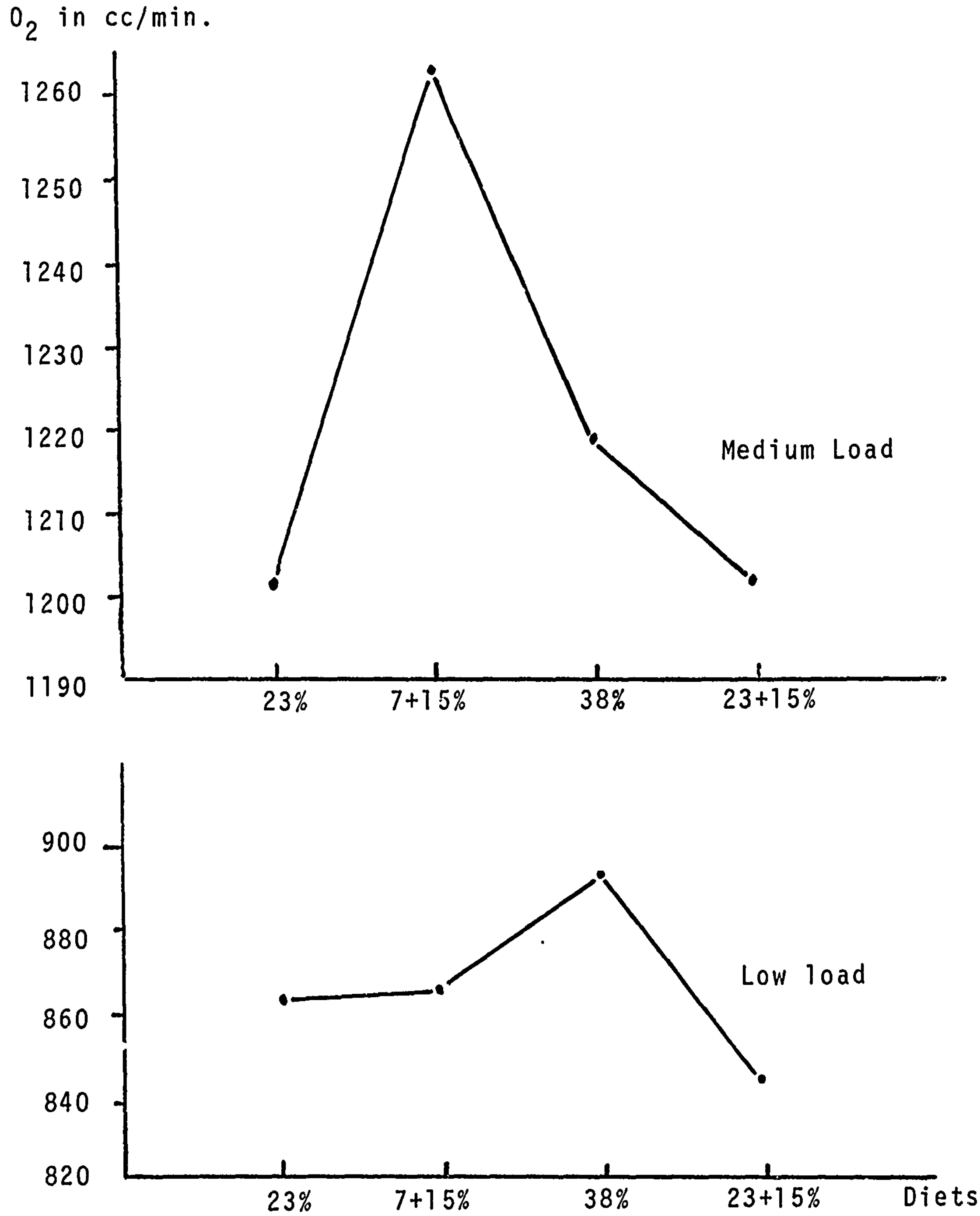


Figure 1. Oxygen Consumption Versus Diets
(Corrected for training effects)

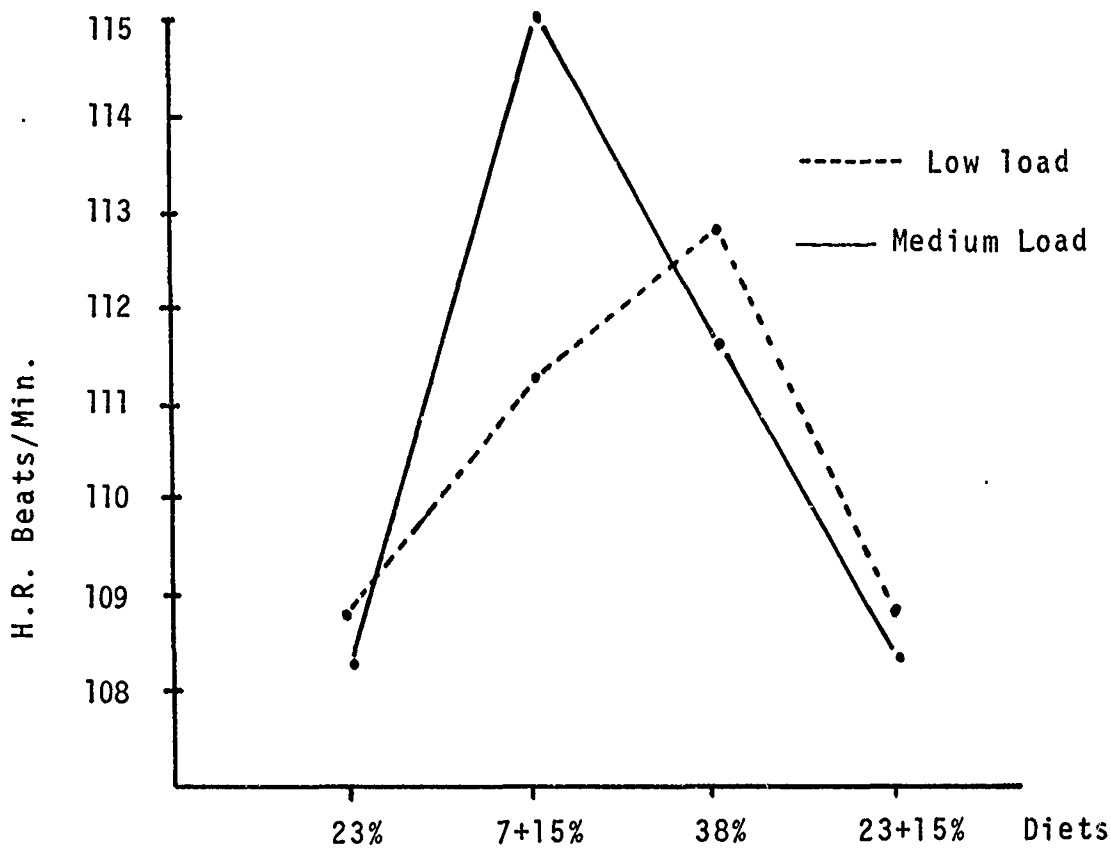


Figure 2. Heart Rate Versus Diets
(Corrected for training effects)

diets, show the lowest "physiological load" on the subject during the activity in terms of heart rate and $O_2$ consumption.

Another significant result is shown in Figures 3 and 4. These figures depict the recovery levels that the subject achieves during a one hour run when the load shifts repeatedly from the medium load to the low load. Figures 3 and 4 illustrate averages for each 5 minute duration. Figure 4 show that after a one hour run it appears that the subject stabilizes and heart rate become assymtotic.

B. The 10-10 physical loading studies: Results similar to those reported in the 5-5 work schedule were found in a second study of alternating physical loading in which a 10-10 loading schedule was utilized. For example, Figures 5, 6 and 7 indicate that the 10-10 work schedule for work periods of 1 hour, 2 hour, and 3 hours duration resulted in a considerable amount of recovery occuring when the subject switched from the medium load to the low load. However, as can be noticed in these figures, a certain amount of build-up of oxygen consumption and heart rate occurs and tends to reach an assymtote both on the high level and the low level of loading. It is of interest to note that after one hour of loading one may compare a one hour run versus the two hour run and the three hour run for both the heart rate and oxygen consumption values. Figures 5, 6 and 7 show that the oxygen consumption and heart rate values for the one hour 10-10 schedule are similar to the corresponding one hour values for the two hour run of the 10-10 schedule but slightly higher than those for the 10-10 three hour schedule. However, comparison of the heart rate and oxygen consumption values at the end of the two hour run for the 10-10 schedule with those for the three hour 10-10 schedule, indicates that the oxygen consumption and heart rate values at the end of each hour of the two hour 10-10 schedule are higher than the corresponding values for the three hour run in the 10-10 schedule. These differences might be attributed to the order in which the experiments were run. The experimentation started with the 5-5

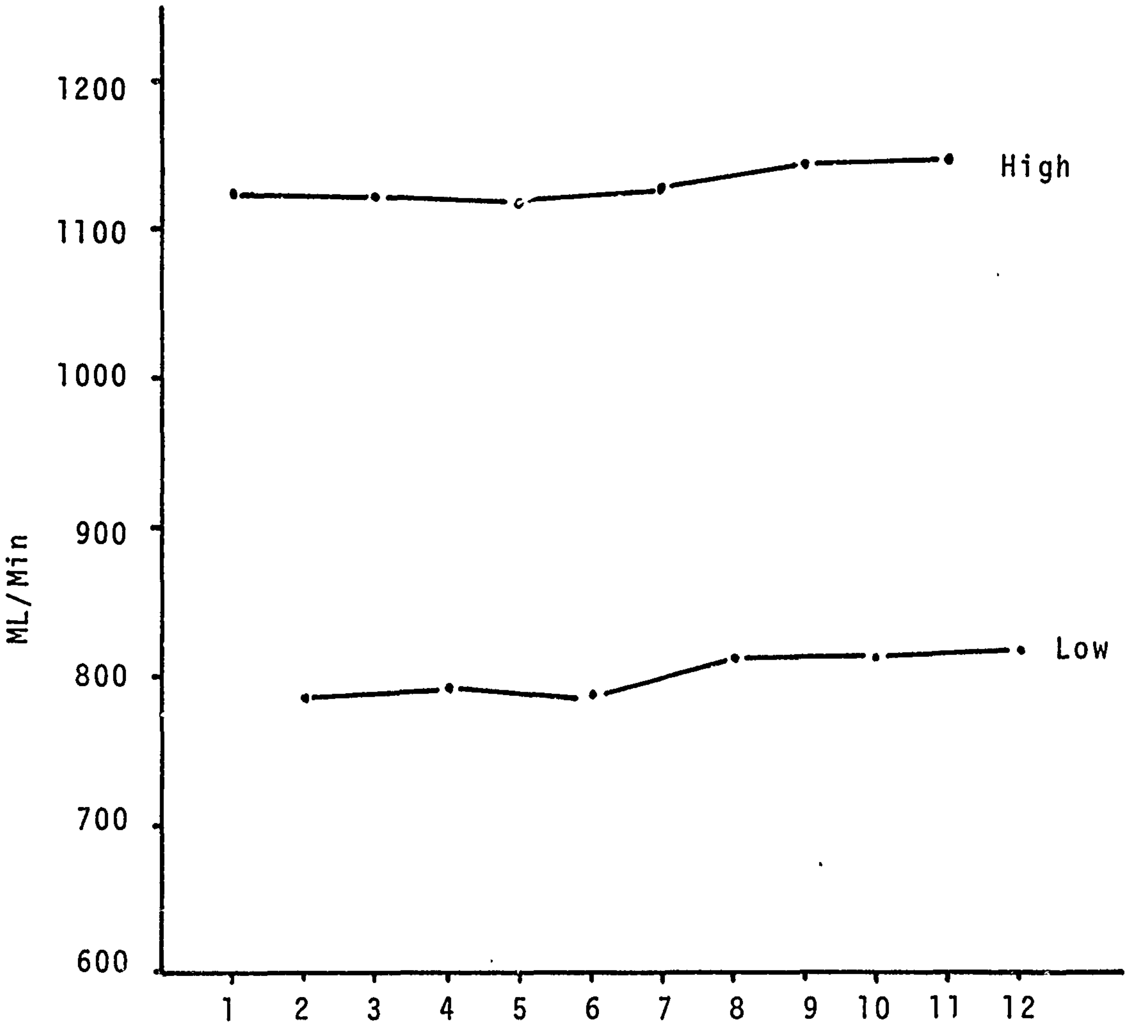


Figure 3. Average $O_2$ Consumption Versus Work Interval (5 min)

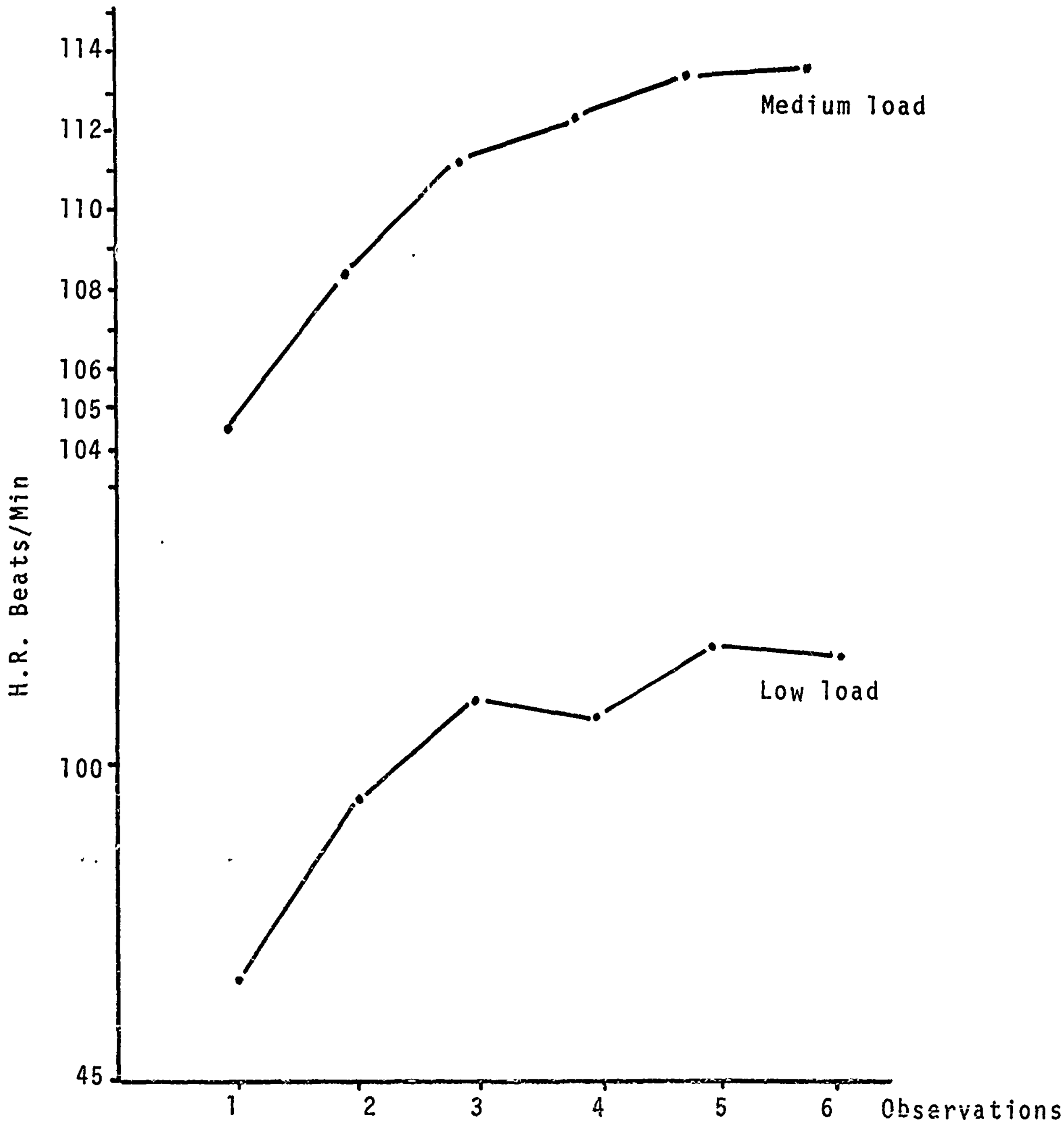


Figure 4. Heart Rate Versus Interval (5 min)

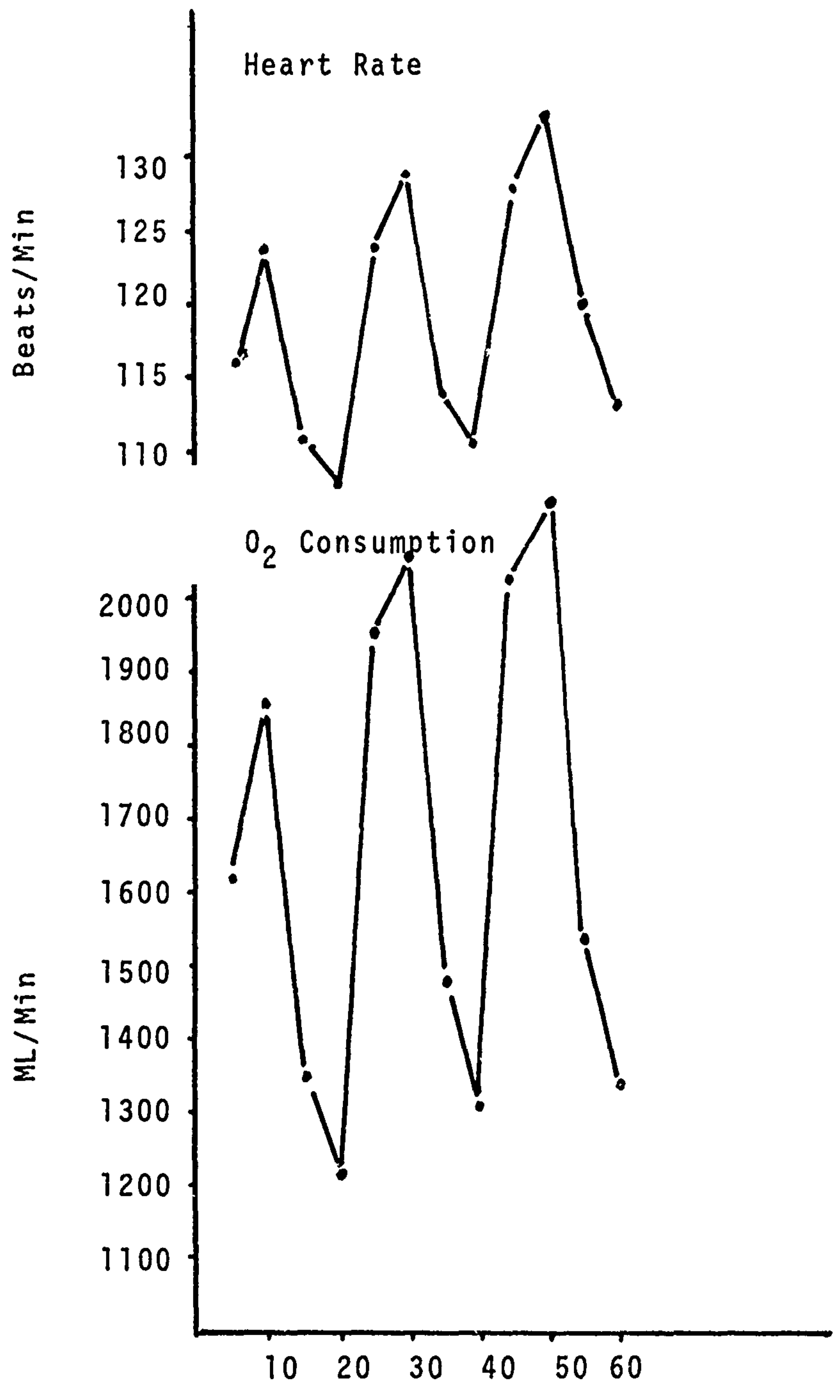


Figure 5. One Hour 10-10 Schedule $O_2$ and H.R. Versus Interval

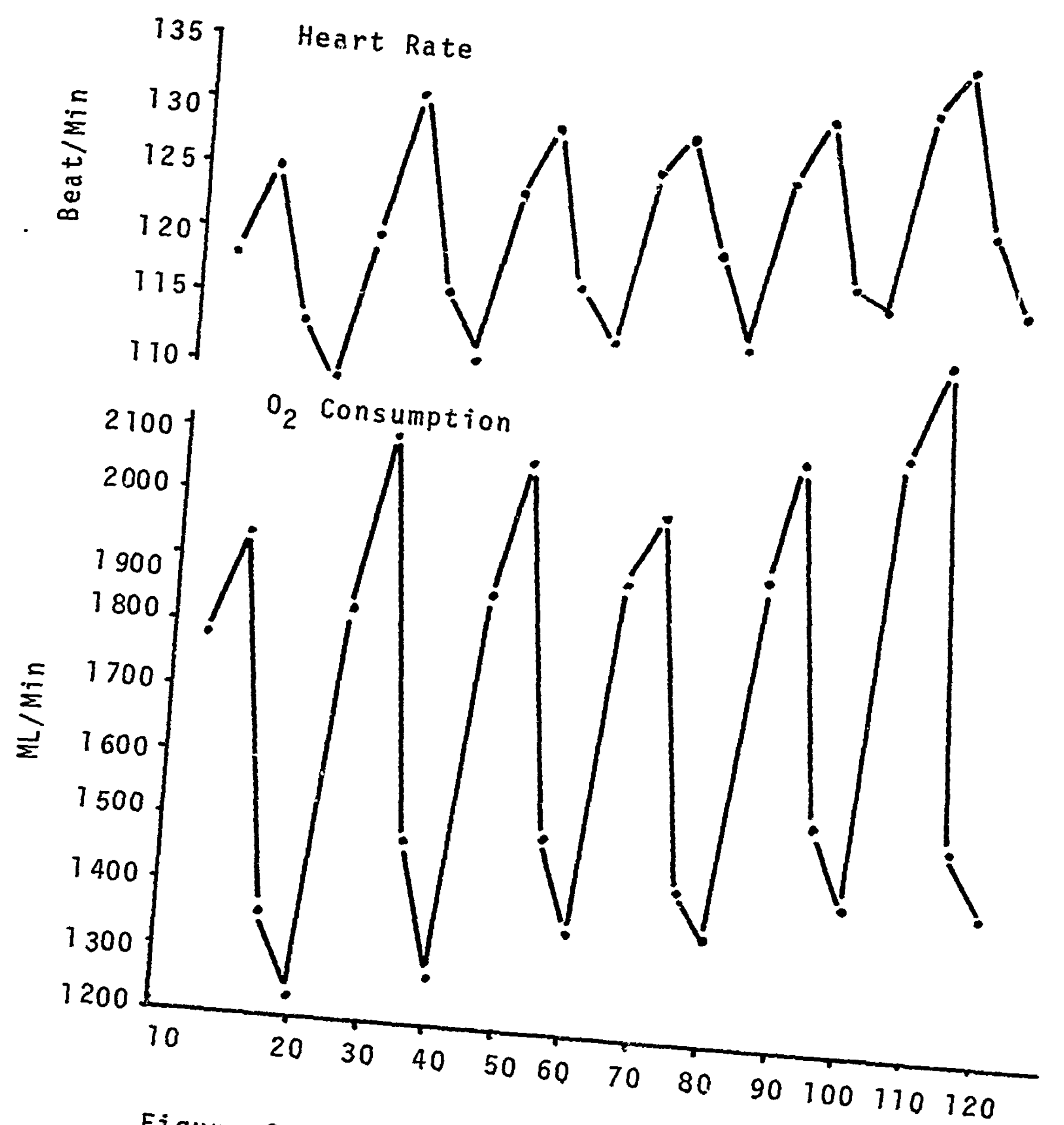


Figure 6. 2 Hour 10-10 Schedule $O_2$ and H.R. Versus Interval

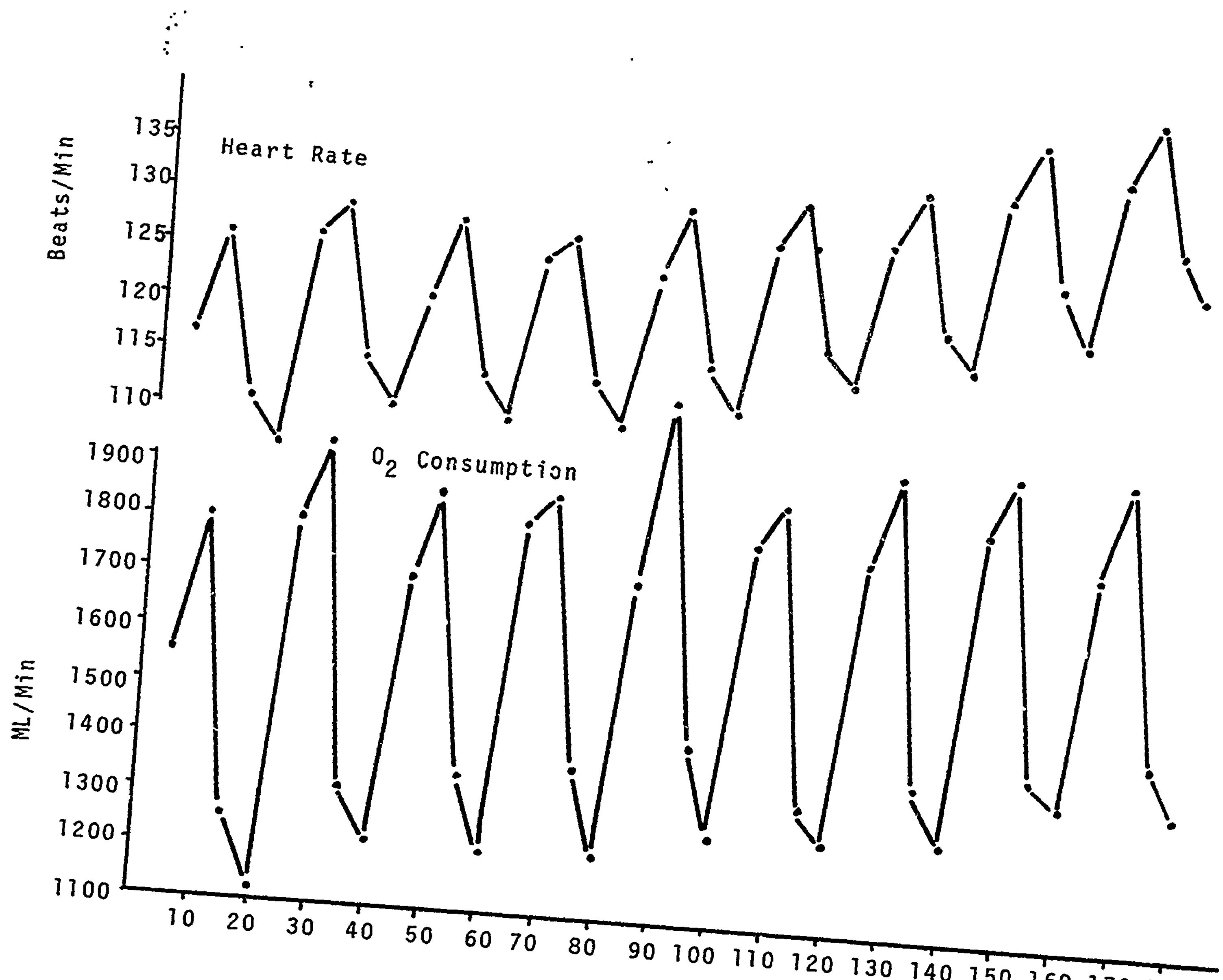


Figure 7. Three Hour 10-10 Schedule $O_2$ and H.R. Versus Interval

schedule, followed by the 10-10 schedules followed by the 15-5 schedule. Similarly, the one hour run was followed by the two hour and then followed by the three hour run Therefore, one would expect that a certain amount of training would occur. However, it is also possible that the subject may be able to slightly change his performance method and posture on the treadmill which may account for the change in heart rate and oxygen consumption. This may indicate that as the body is further stressed, the individual may strive to achieve the optimum performance method available so as to minimize his energy expenditure and hence the accumulative effects.

C. 15-5 physical loading study: A 15-5 loading schedule was used in the third study of alternating physical loading. The results from this schedule are similar to those found for the 5-5 and 10-10 loading schedules. Figures 8, 9 and 10 show that considerable recovery takes place as the subject alternates from the high load to the low load. Again, there is a certain amount of accumulation of oxygen consumption and heart rate as the subject progresses in the work period. In comparing corresponding hours for the one hour run, the two hour run, and the three hour run, one finds similar results as those reported in the 10-10 schedules in that at the end of the one hour loading session a heart rate of 122 beats per minute and oxygen consumption of 1480 ml/min. occur as compared to a heart rate of 119 beats per minute and an oxygen consumption of 1460 ml/min. for the two hour schedule and a heart rate of 114 beats per minute and an oxygen consumption of 1500 ml/min. at the end of one hour for the three hour schedule. This indicates that apparently there is either a training affect similar to that mentioned in the 10-10 schedule or the subject changes his posture or method of performing the walking on the treadmill which may alter his oxygen consumption to achieve a lower physiological cost. Similar statements can be made in comparing the heart rate and oxygen consumption at the end of a two hour run for the 15-5 schedule with the heart rate and oxygen consumption values recorded at the end of 2 hours of the 3 hour run for the 15-5 schedule.

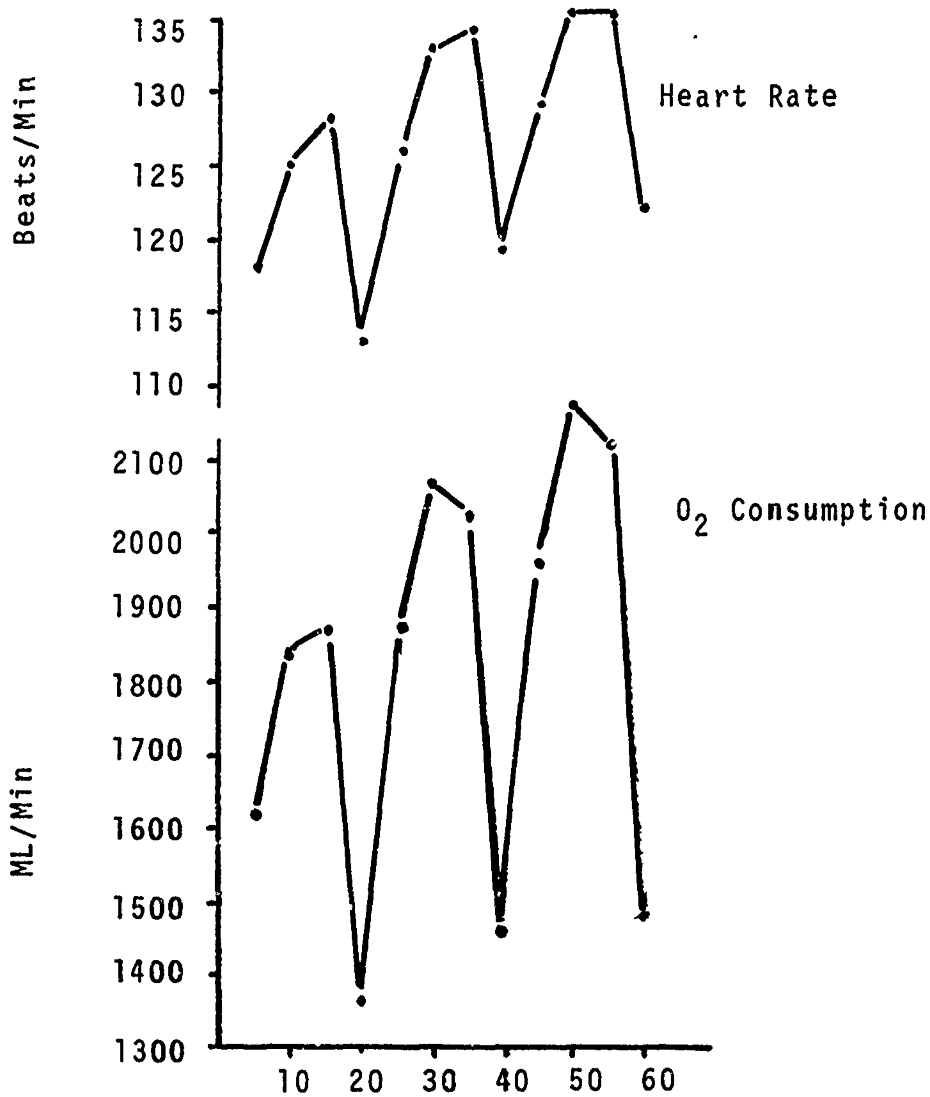


Figure 8. One Hour 15-5 Schedule $O_2$ and H.R. Versus Interval

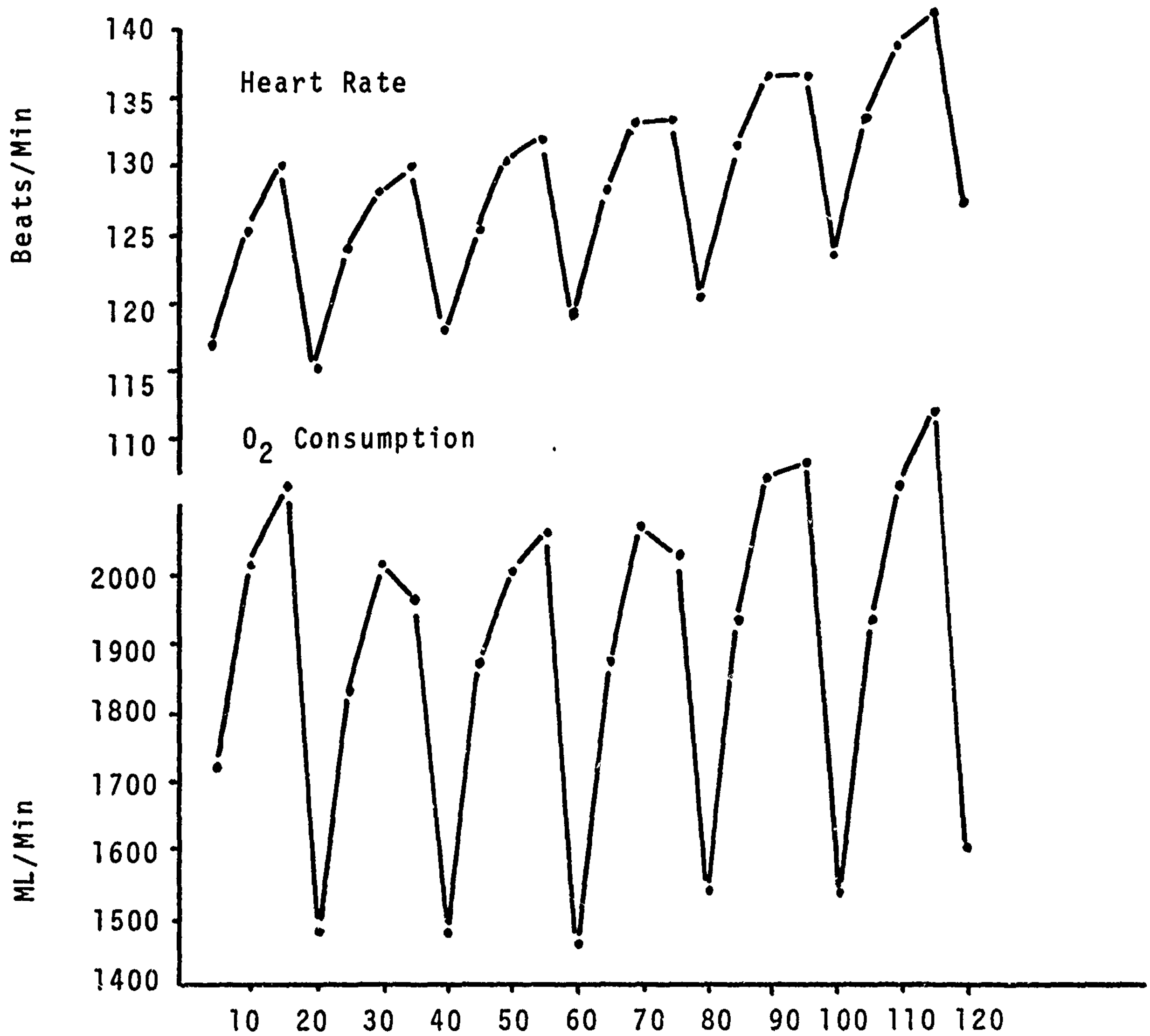


Figure 9. Two Hour 15-5 Schedule $O_2$ and H.R. Versus Interval

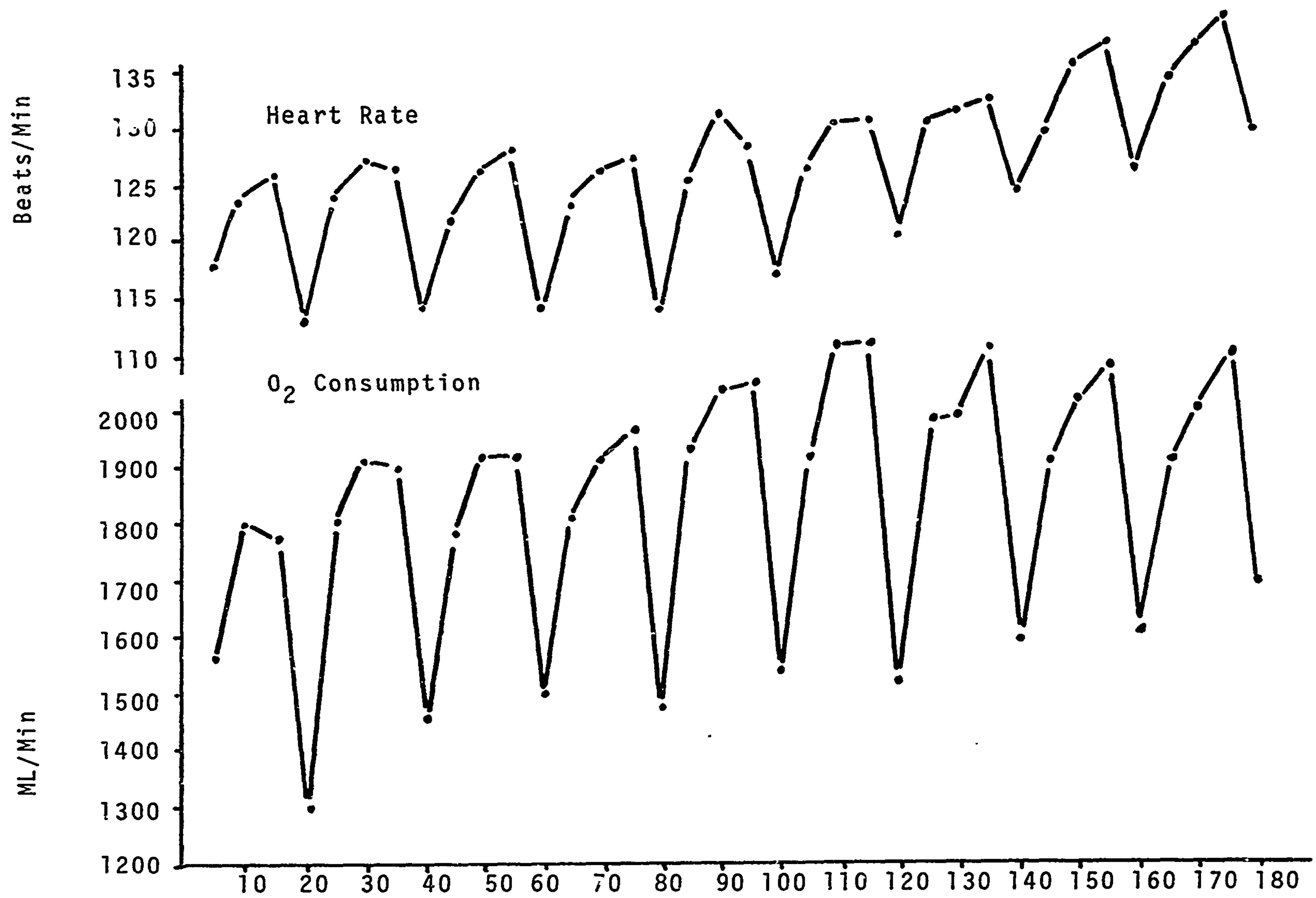


Figure 10. Three hour 15-5 Schedule $O_2$ and H.R. Versus Interval

In Figures 11 and 12, the values for the 2 hour and 3 hour runs of the 10-10 and 15-5 schedules are superimposed. Inspection of Figure 11 indicates that the mean oxygen consumption and heart rate scores for the medium loads for both the 10-10 and 15-5 schedule for the 2 hour run differ by a small amount (approximately 650-700 ml/min. for oxygen consumption and approximately 5 beats/min. for the heart rate). In comparing the differences for the low level of loading under the 10-10 and 15-5 schedules for the 2 (shown in Figure 11) the difference between the 15-5 and 10-10 schedules account for approximately 4 heart beats/min. and approximately 100 ml/min. of oxygen consumption. However, when comparing the 10-10 and 15-5 schedules for the 3 hour run on the medium load and the low load, one would notice that at the medium load, the differences rose to 100 ml/oxygen/min. and the heart rate changed by approximately 2 beats/min. In comparing the low level of loading one would note that oxygen consumption was changed by approximately 200 ml/min. of oxygen, i.e., it has doubled, while the heart rate changed by approximately 5 beats/min. This indicates that the subject under the 15-5 schedule apparently does not recover as much as he would under the 10-10 schedule. This is expected since he is only working for a 5 minute period under the low level of loading and does not have as long to recover as in the 10-10 schedules.

It is also interesting to note that the heart rate and oxygen consumption values between minutes 10 and 15 for the medium level of the 15-5 schedule for hours one and two of the one, two and three hour runs do not differ markedly. Heart rate and oxygen consumption values tend to plateau after minute 10. This trend does not occur in the third hour of the 15-5 schedule, indicating that a build-up of fatigue might be occuring after the second hour of work.

Eight and Sixteen Hour Day

The results of the 8 and 16-hour work day are decided in Figures 13 thru 18. Results in all Figures illustrates the fact

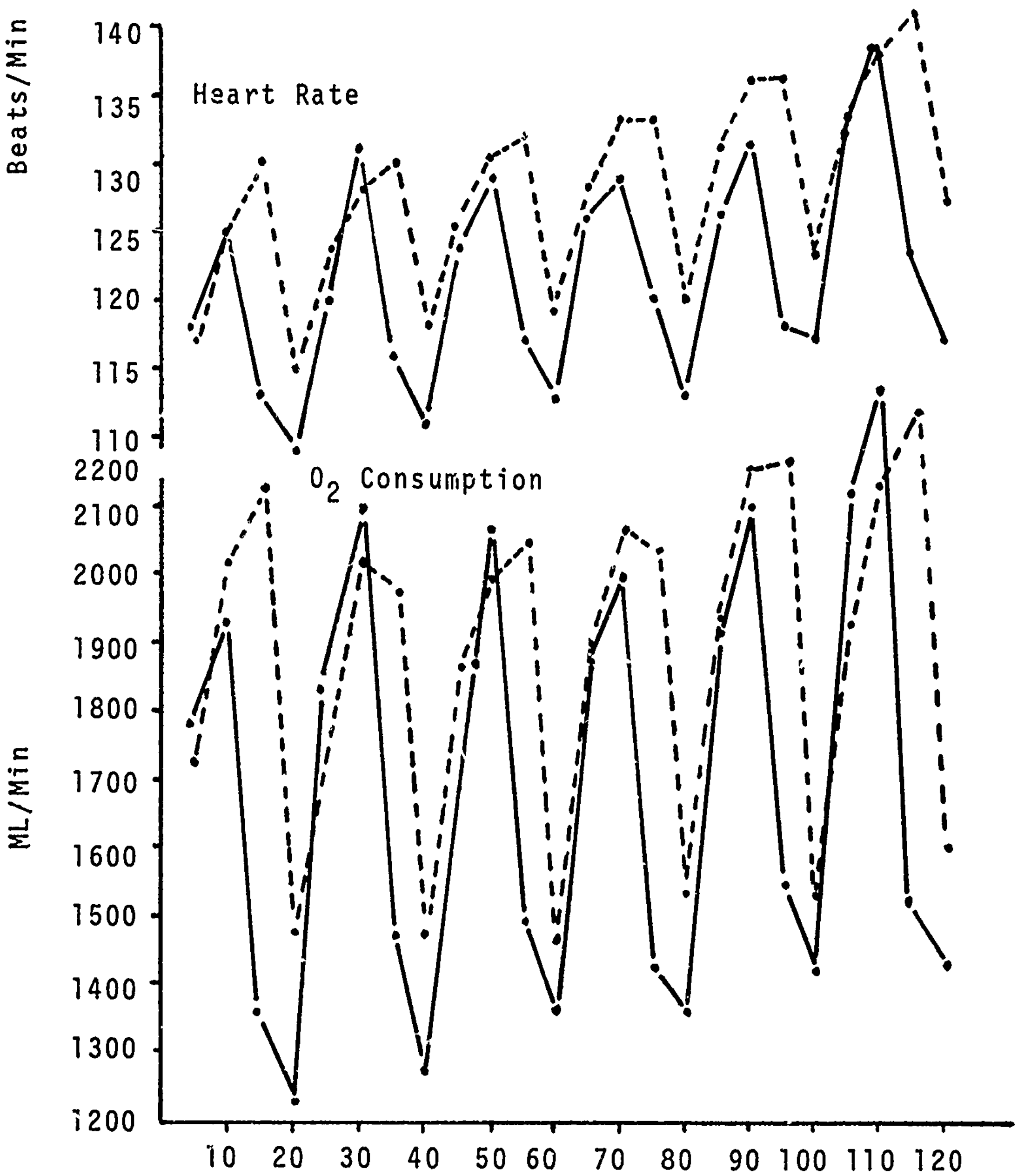


Figure 11. Two Hour 10-10, 15-5 Comparison $O_2$ and H.R. Versus Interval

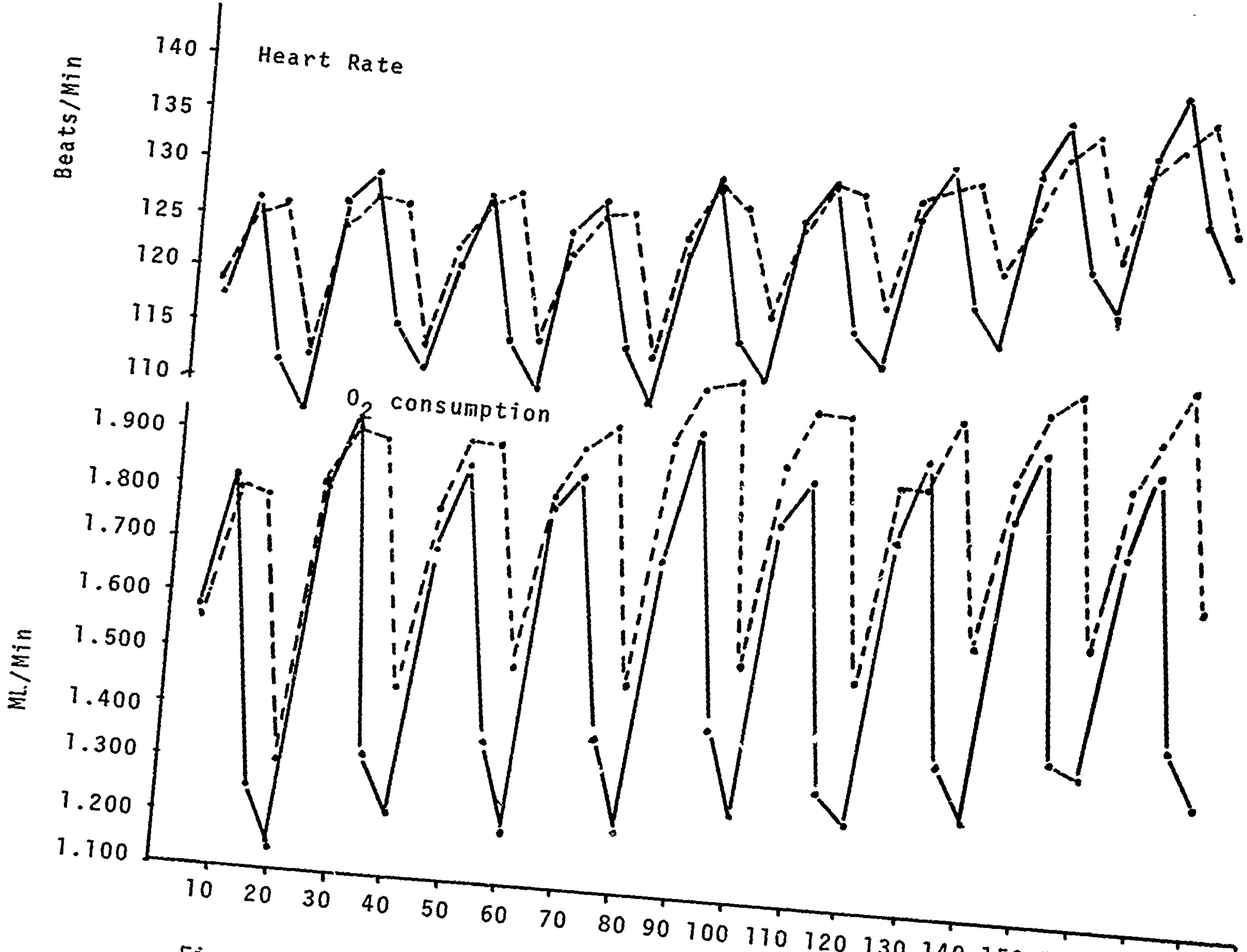


Figure 12. Three Hour 10-10, 15-5 Comparison $O_2$ and H.R. Versus Interval

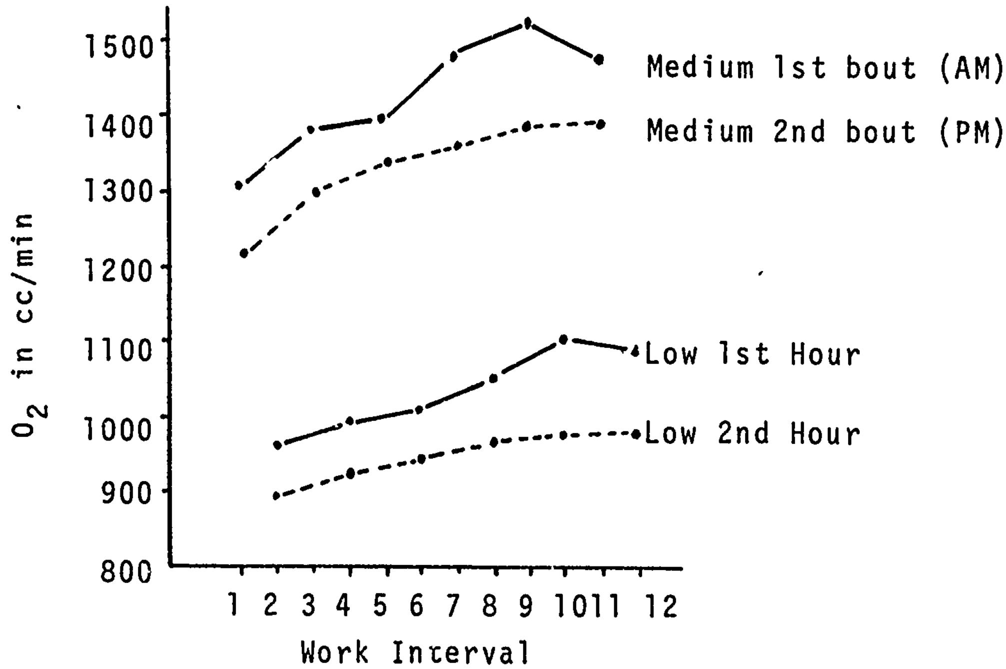


Figure 13. Oxygen consumption, 1st & 2nd work bout, 8-hour day.

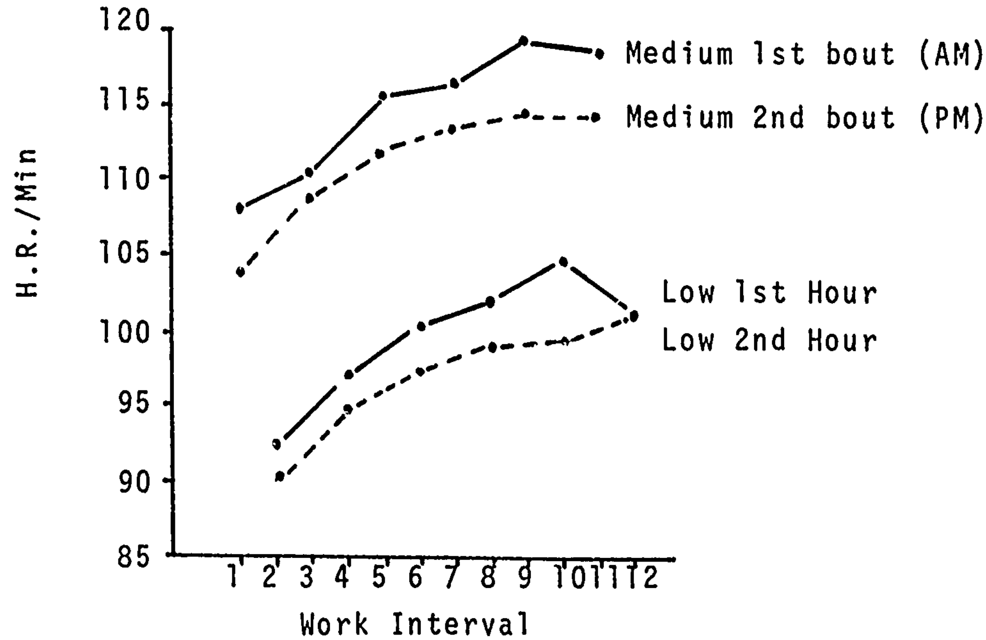


Figure 14. Heart rate, 1st & 2nd work bout, 8-hour day.

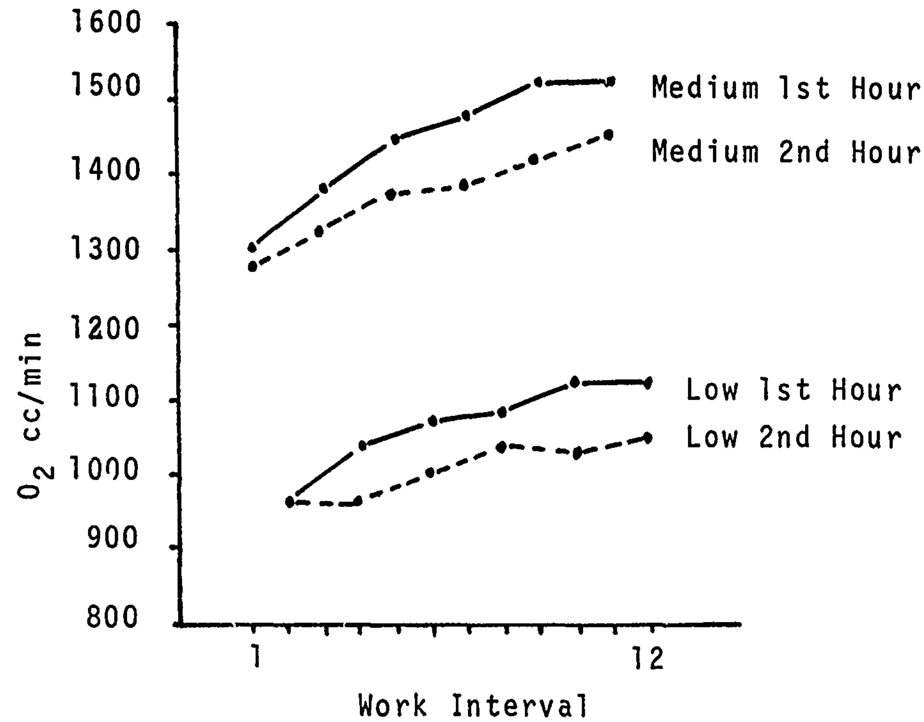


Figure 15. Oxygen consumption, 1st & 2nd work hour, 16-hour day.

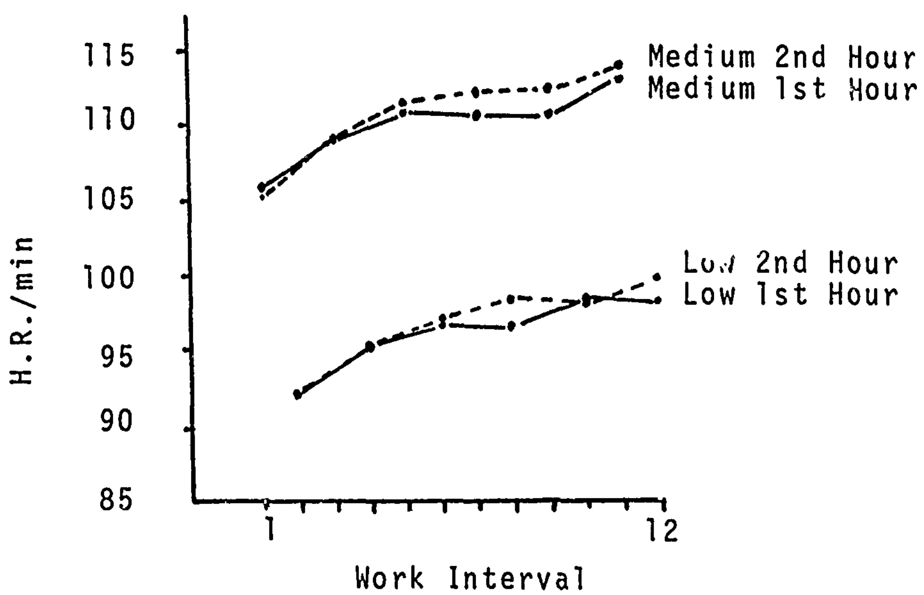


Figure 16. Heart rate, 1st & 2nd work hour, 16-hour day.

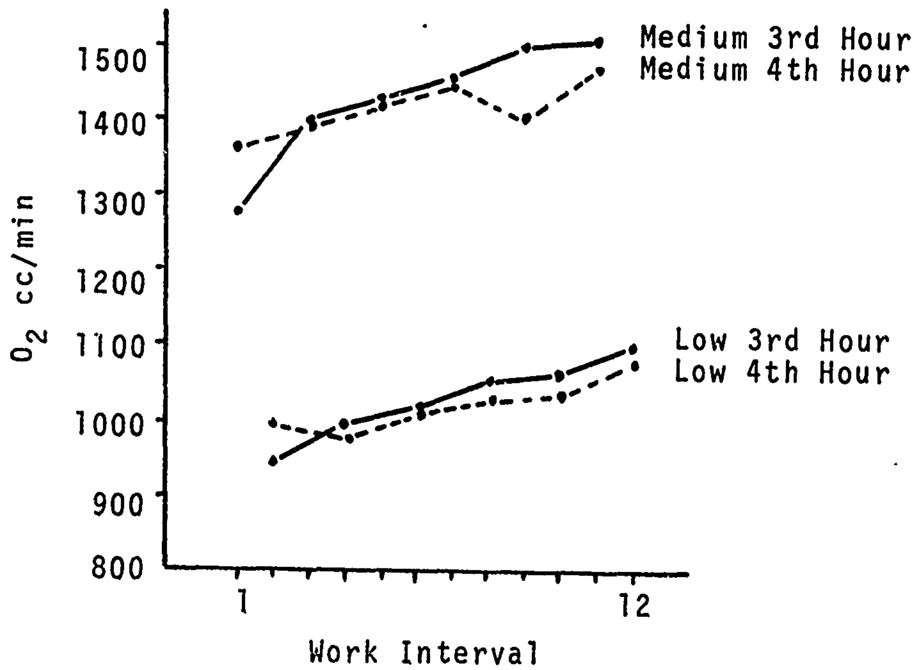


Figure 17. Oxygen consumption, 3d & 4th work hour, 16-hour day.

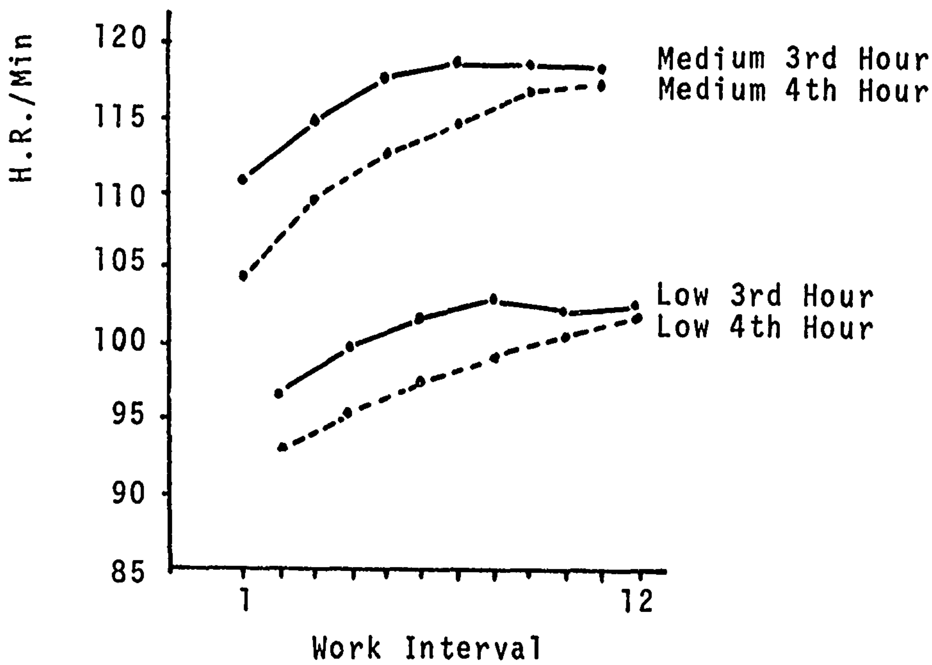


Figure 18. Heart rate, 3d & 4th work hour, 16-hour day.

that a progressive build-up in oxygen consumption and heart rate occured in both the medium and low work levels for each work interval. It is interesting to note, however, that the starting and concluding work costs for the second work bout in both the 8 and 16-hour day are lower than those for the first bout of work. (Figures 13-16). Apparently a physiological adjustment occurred during the first rest interval that enable the subjects to start and conclude the subsequent work period at lower physiological requirements. This trend was not continued during the third and fourth work periods of the 16-hour day (Figures 17 and 18). A progressive increase, from starting to concluding 5-minute runs in both criterion scores was observed in the latter two one-hour bouts.

Although the build-up during the third and fourth bouts of the 16-hour day was greater than that in the two preceeding bouts, (first and second) the magnitude of the differences was not very large. Figures 17 and 18 illustrates these differences. The starting oxygen costs, medium and low, for bout three were almost identical to those for second bout. Corresponding heart rate values differed by approximately 5 beats per minute. Differences between subsequent 5-minute values were larger, 50-60 ml (for the medium load and low loads during the last 5-minute periods), and 5-6 beats per minute.

Similar results were observed between second, third, and fourth bouts with the trend toward a higher build-up occurring during the fourth bout. Starting oxygen consumption values for both loads (30-40 ml/min.) in bout four higher than for bout three. Post-work values were closer than the starting values.

The results of this investigation indicate that subjects can tolerate a 16-hour work day of the type examined in this study without any appreciable build-up of oxygen and heart rate requirements.

Results of the 24 Hour Day

As previously described, the twenty-four hour study was designed for two subjects to work at 30% of aerobic capacity for one hour out of every two hour work period. The subject was given nourishment during a one hour break after every four hours (2 -2 hour periods) of work. The schedule was continued for twenty-four hours or until the subject could not continue. One week later, the subjects repeated the twenty-four hour day working at 50% of aerobic capacity. The other two subjects had the same schedule except they worked at the 50% level first and one week later worked at the 30% level.

The complete findings of the study are not available as it is in the analytical stage. However, selected statistics and data have been plotted to provide partial and/or speculative results.

The following four figures (19,20,21, and 22) are presented to illustrate the effect of the continuous work schedule on the net physiological cost of the task for each of the four subjects. It can be observed that none of the four subjects were able to complete the 24-hours at the 50% level and that one of the four was unable to complete the 24 hours at the 30% level. Local muscular fatigue or injuries related to the task resulted in the early termination of the subject's 24 hour work day.

Examination of the mean net physiological cost (figure 23) over the twenty-four hour day reveals that the design, which included a minimum of one hour of rest between work periods allowed the subjects sufficient rest recovery time to deter accumulation of fatigue. From the same figure (figure 23) it can be observed that the food taken every four hours, or the rest associated with the nourishment,did affect the net physiological cost of the two succeeding 50% work periods. The mean net physiological cost immediately following the meal was slightly higher than the succeeding work period. This

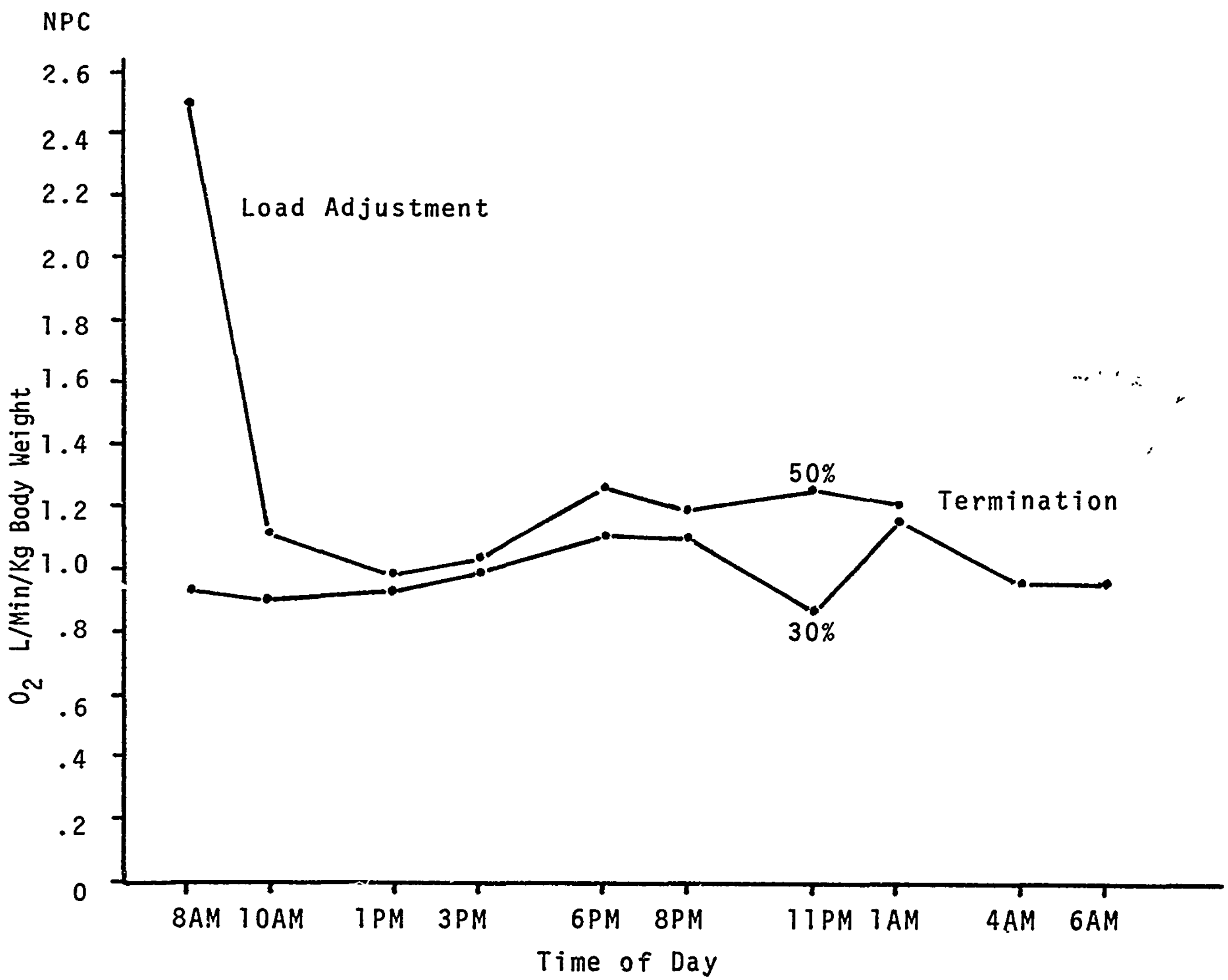


Figure 19. Net Physiological Cost Versus Time of the Day (Farley)

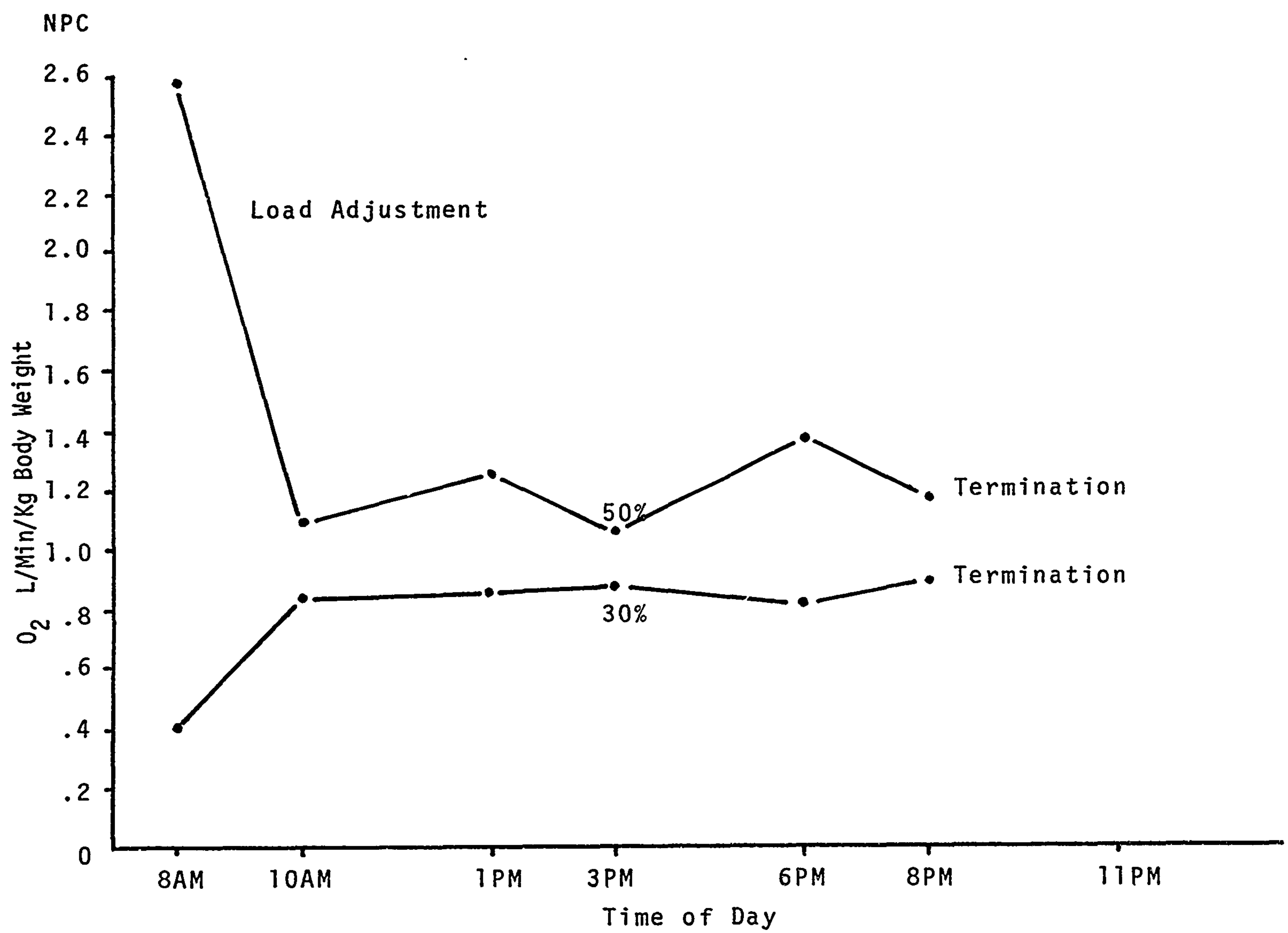


Figure 20. Net Physiological Cost Versus Time of Day (Sublette)

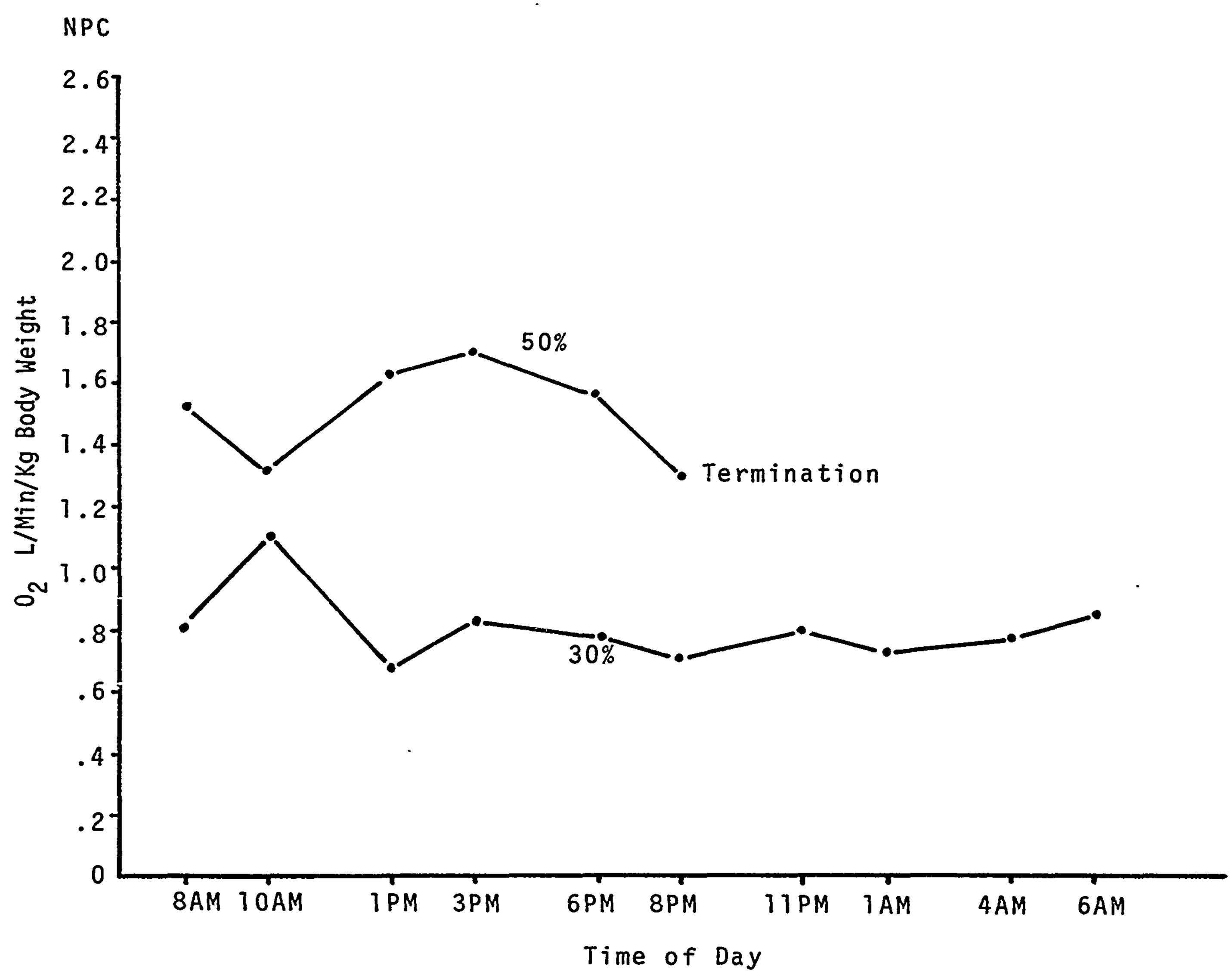


Figure 21. Net Physiological Cost Versus Time of Day (Phillips)

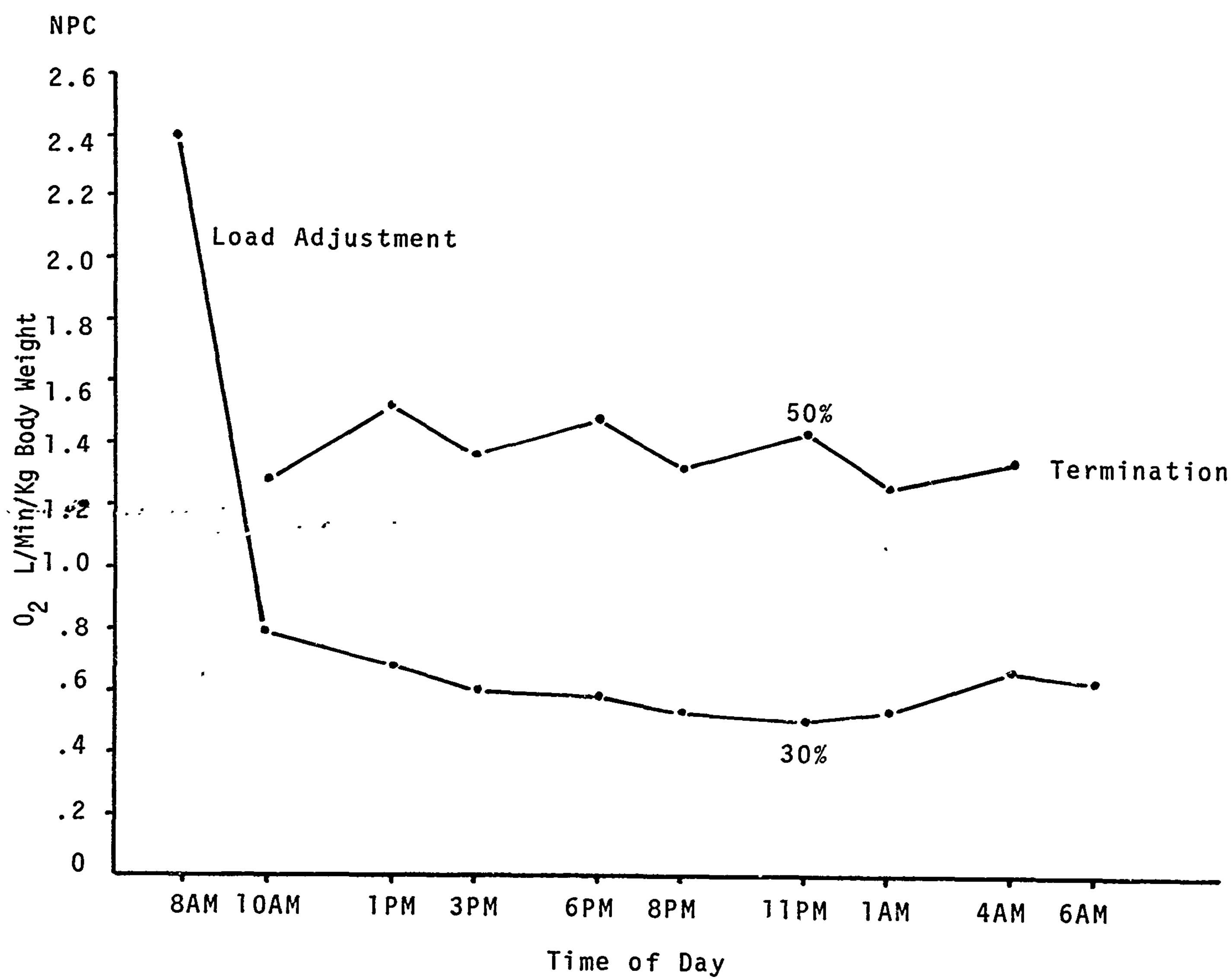


Figure 22. Net Physiological Cost Versus Time of Day (Johnson)

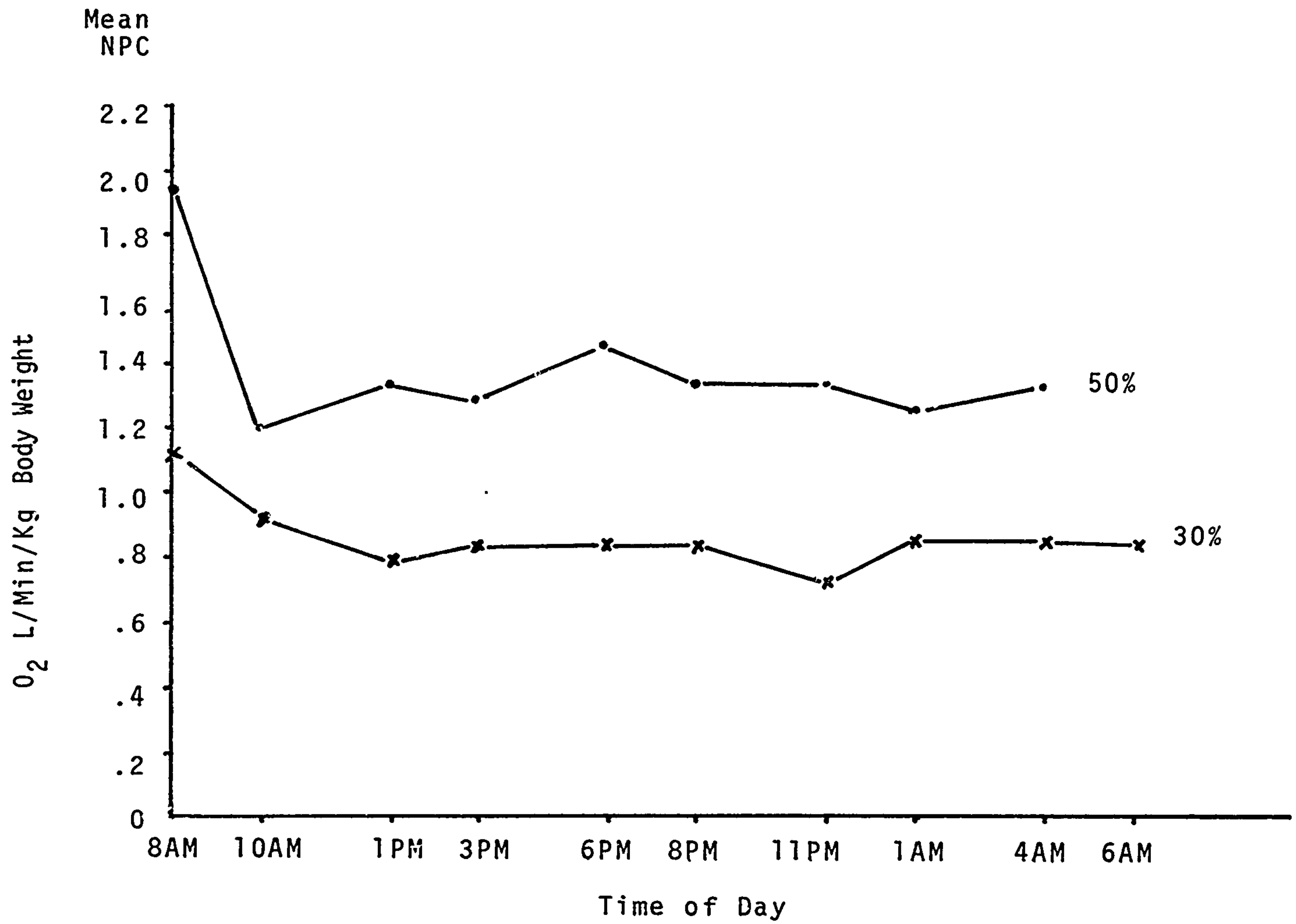


Figure 23. Mean Net Physiological Cost

observation may have resulted from (1) Increased $O_2$ consumption resulting from the digestive processes, (2) an increased temperature after eating or (3) a change in effeciency in performing the treadmill task.

At the 30% and 50% level of work, an increase in $O_2$ uptake was observed when 5 minute $O_2$ consumption intervals within the hour of work were plotted. This was especially true in the 4th and 6th work periods (3 to 5 PM) and 8 to 10 PM) of the 30% level and 2nd and 4th periods of work (10 to 12 AM and 3 to 5 PM). (See figures 24 and 25.)

Similar results can also be observed for the heart rate data. Figures 26 and 27 show the accumulative effects within each work period. For the 30% and 50% levels definite increases during each one hour run occur at varied degrees dependent on the time of the day each run was made. Figures 26 and 27 also reveal an accumulation effect on heart rate over the twenty-four hour day.

Normally, the heart rate does show accumulative effects during a constant working task, but when the task is at the 50% level or less the $O_2$ uptake does not. In this study, accumulative effects in $O_2$ uptake were observed in a few runs. No explanation for the observations are presented at this time. Figure 10 illustrates the accumulative effects.

## Summary of Observations

1. The subjects were able to work for twenty-four hours with periodic rest and nourishment, without an accumulative effect on his net physiological cost.

2. Nourishment taken between work periods (at the 50% level) appears to have an effect on the net physiological cost in succeeding work periods.

3. Accumulative effects at the 30% and 50% level were apparent in heart rate both within a work period and

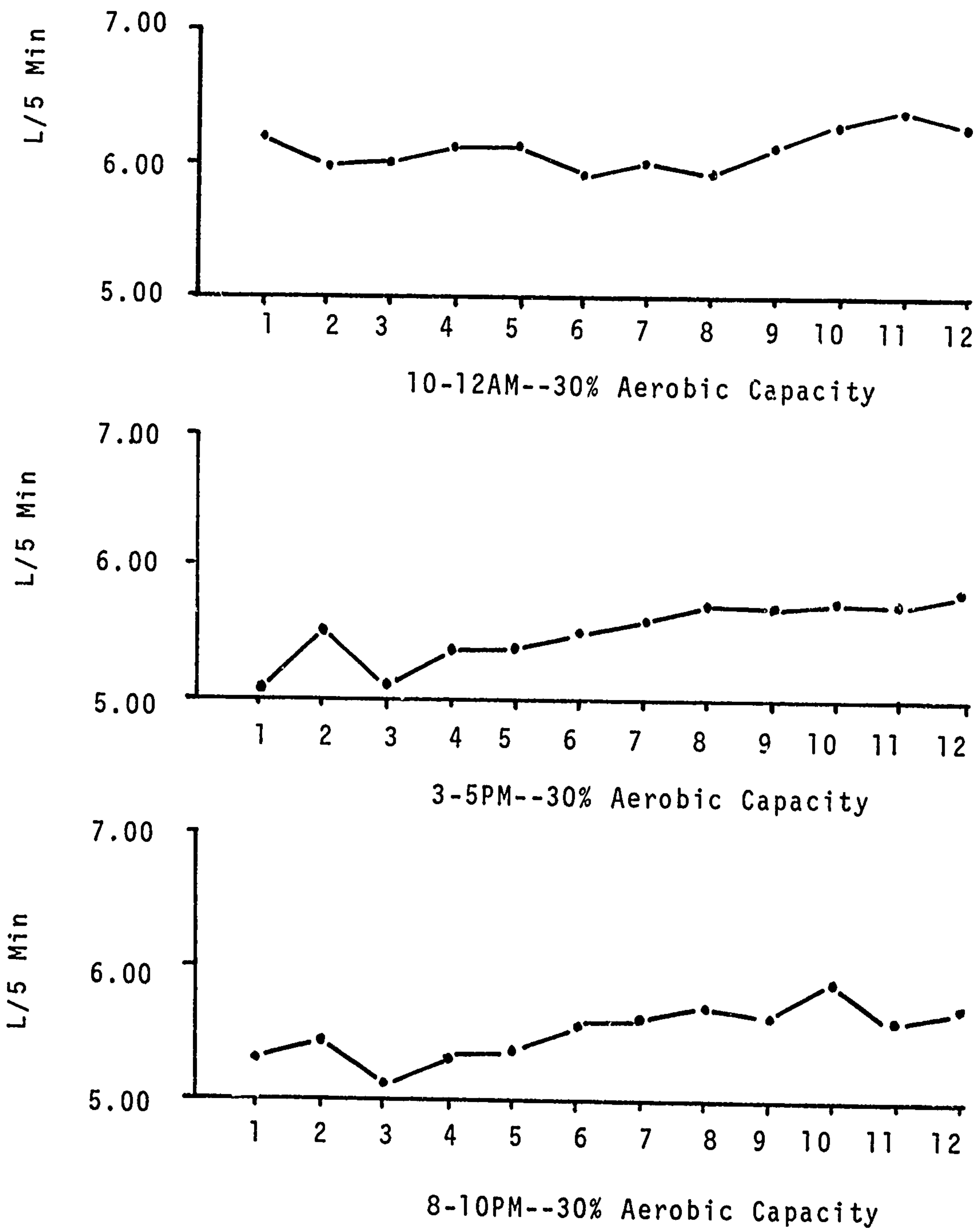


Figure 24. Mean $O_2$ Consumption - L/5 min

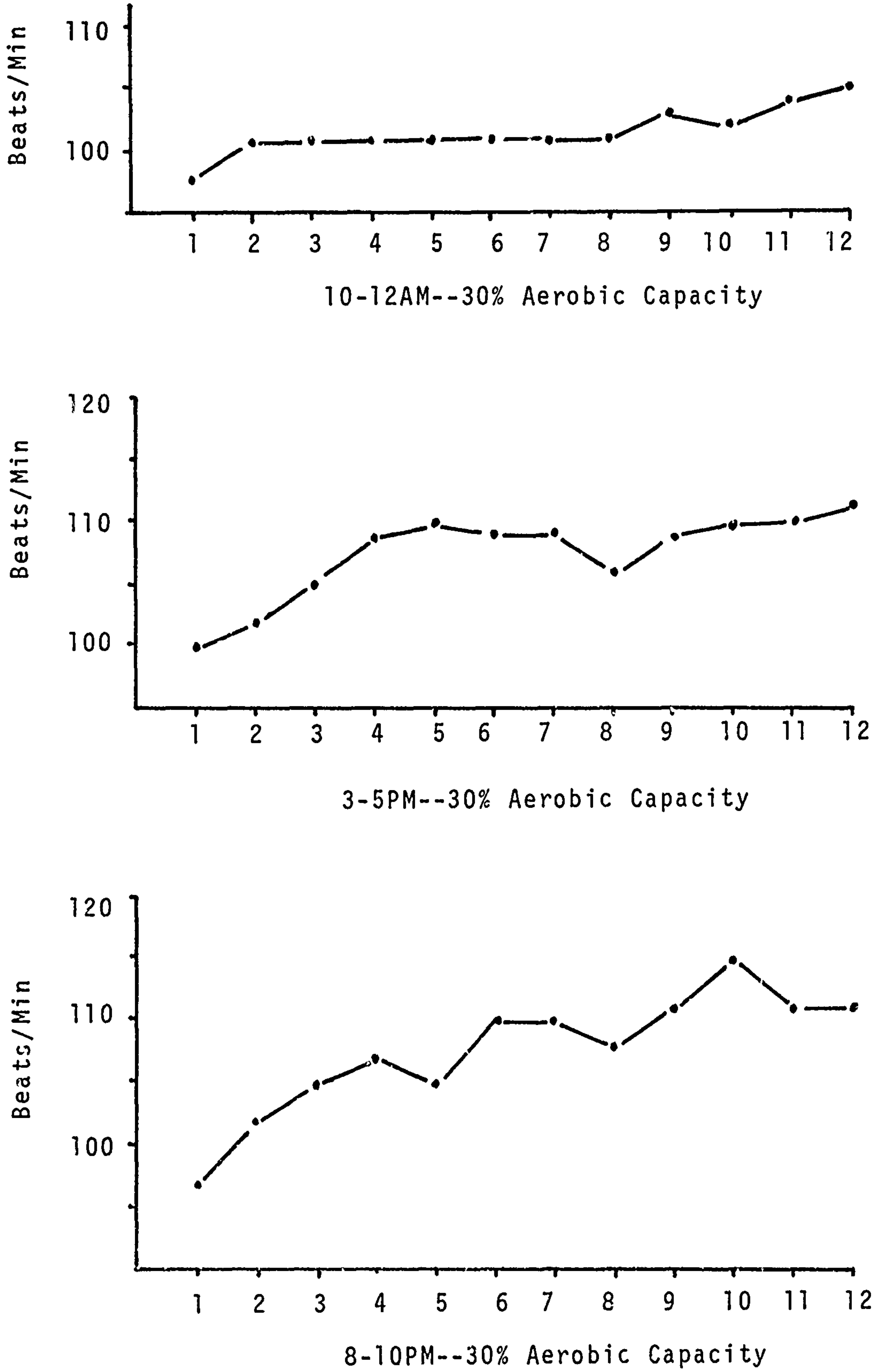


Figure 25. Mean Heart Rate - B/min

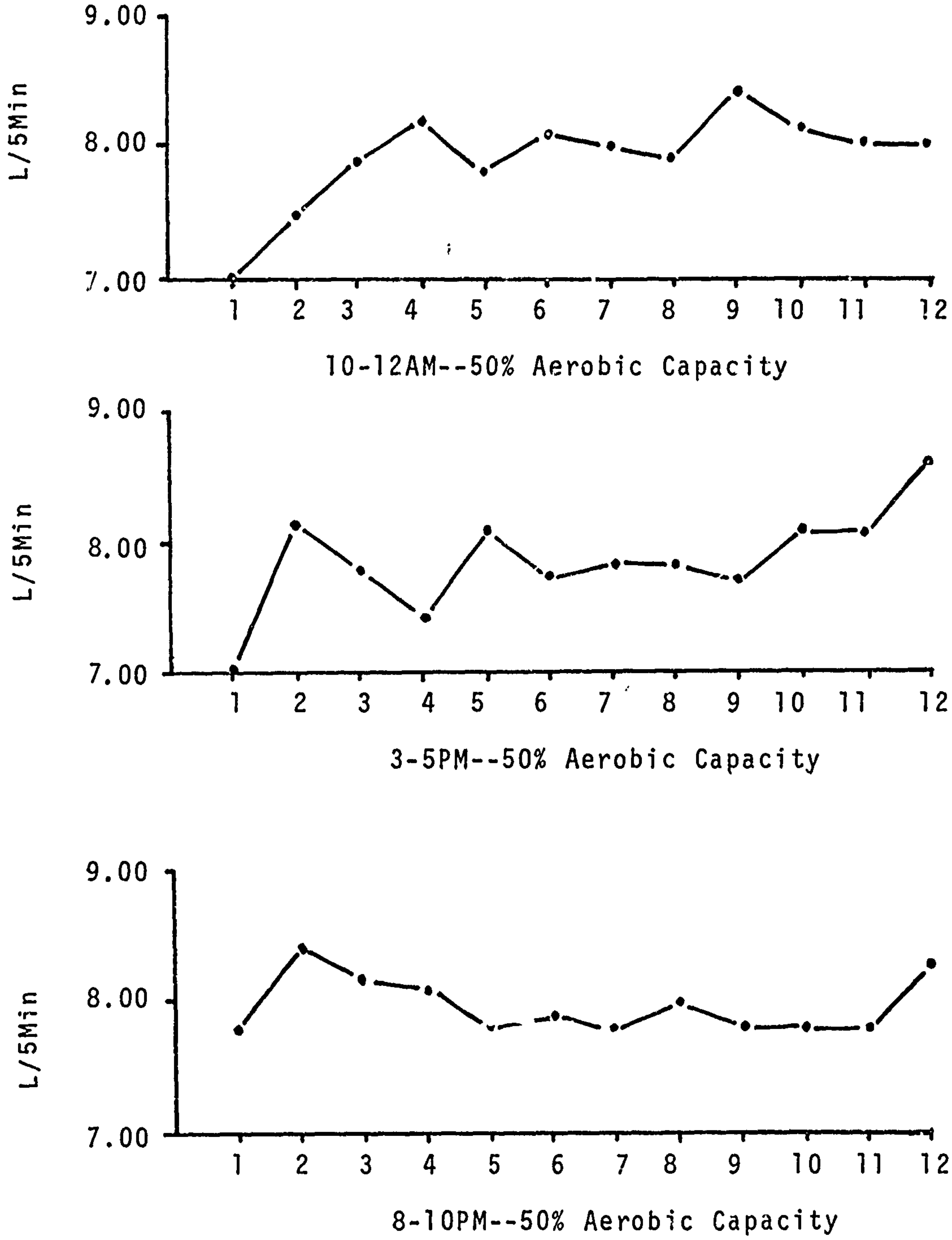


Figure 26. Mean $O_2$ Consumption - L/5 min

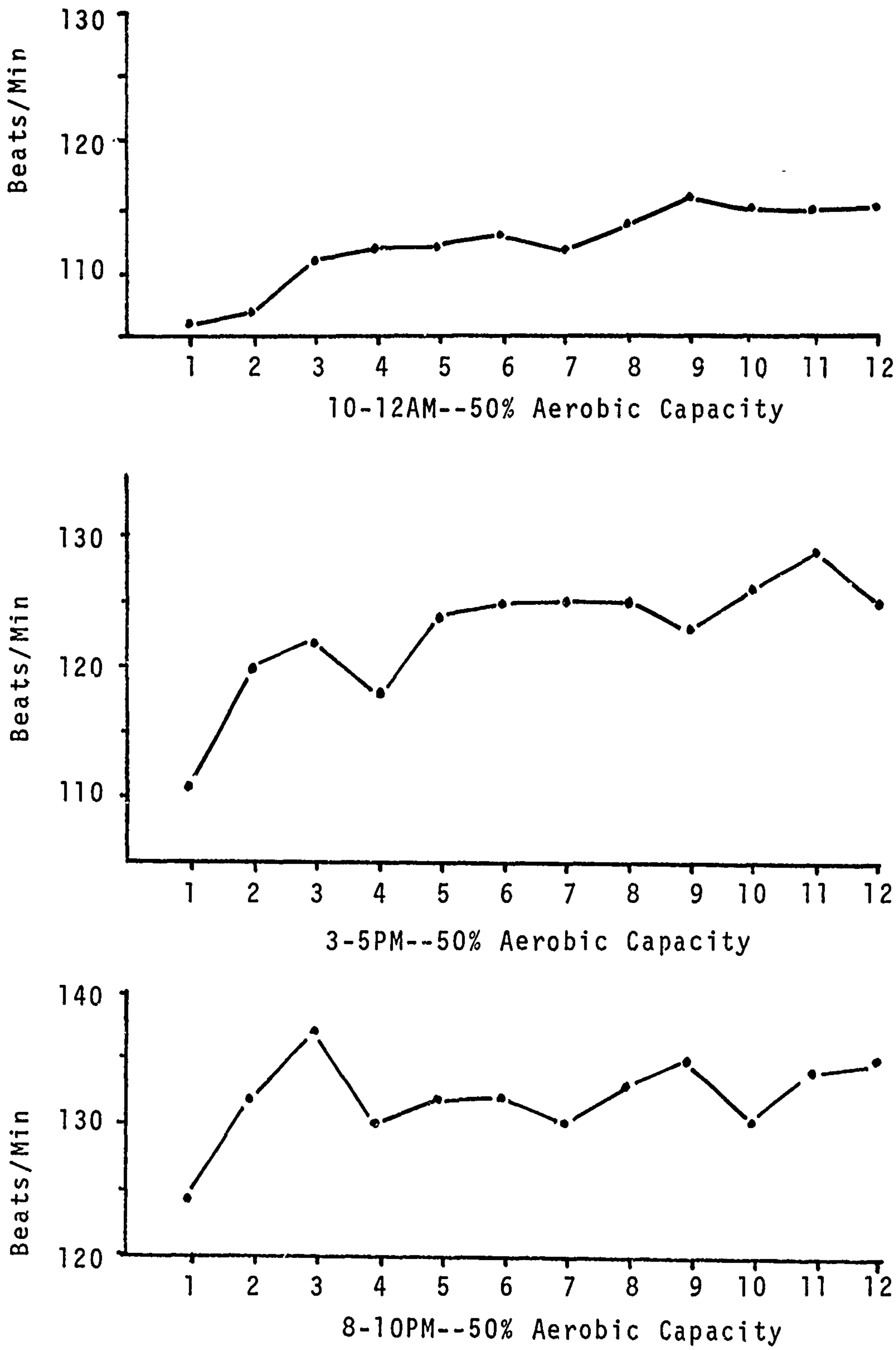


Figure 27. Mean Heart Rate - B/min

also from one work period to another throughout the twenty-four hours.

4. Accumulative effects were apparent in the $O_2$ uptake with the 50% work periods.

<u>Effects of Circadian Rhythms on Muscular Performance</u>

The same physiological measurements were made on seventeen subjects participating in four separate experiments: The 8 and 16 hour and 24 hour studies previously presented plus a tracking task and a separate alternating physical loading experiment. The alternating physical loading study using the treadmill followed essentially the same procedure that was previously described. In this study, however, fixed loads of 2 and 4 mph were used. Five subjects were scheduled to walk for an hour at three different times of the day with a total of two runs at each time. In the tracking task, four subjects performed a vertical compensatory tracking task using a cathode ray tube. Each subject worked for an hour at nine different times of the day on two week ends. During the week, each subject worked 35-50 minutes for the same two time periods of the day which were 4 hours apart. The work periods were different for each subject.

Each of the seventeen subjects recorded his oral temperature, measured his heart rate and took a urine specimen at intervals throughout the day. In addition, he kept a daily log of his activities and diet. Urine from all studies except the 24 hour experiment has been analyzed for urea-nitrogen, uric acid, creatinine, inorganic phosphate, and chloride using a Technicon AutoAnalyzer. An aliquot of urine obtained during the 24 hour study has been frozen for analysis by the AutoAnalyzer. Sodium and potassium analysis of the urine is currently being made with an EEL integrating flame photometer.

The values obtained from the urinalyses and the data on heart rate and body temperature is soon to be analyzed for the presence of rhythms by Dr. Franz Halberg of the University of

Minnesota. The oxygen consumption and heart rate values measured during the treadmill studies and the error scores from the psychomotor task in the 8 and 16 hour study and from the tracking task will also be examined for rhythms.

A preliminary evaluation of some of the performance data has been made using analysis of variance with each subject treated as a block to remove the effects of individual variation. Figure 28 shows the average values obtained for oxygen consumption and heart rate during the alternating physical loading experiment. Both show decreased values for the afternoon runs. If the averages for each individual are examined however, additional patterns are present. In Figure 29 two subjects show decreased $O_2$ consumption during the middle time period while two show continuously decreasing values and one shows a slight rise. This graph is somewhat misleading, however, since scheduling problems made it necessary for two subjects to make their runs two hours before the other three. Thus it is possible that if a run for them had been made at or later than the last run show, they would have shown increased oxygen consumption later in the day also.

The average values for heart rate of each individual show a similar dip (Figure 30) for three subjects who worked at the same time of day. Thus it is again possible that the two subjects which appear not to conform might show an increase if a later measurement had been taken.

Plots of $O_2$ + HR for individuals at 2 or 4 mph show more variability but most show the trend of steady decrease or a decrease followed by a rise. Values for HR are more variable than for $O_2$ consumption.

Although the data from the 8 and 16 hour study has not been analyzed in the same manner, plots of individual means versus day of week show some similarities (Figures 31-34). Values from the 16 hour days often show a decrease in the early afternoon and the 8 hour days generally show decrease from morning

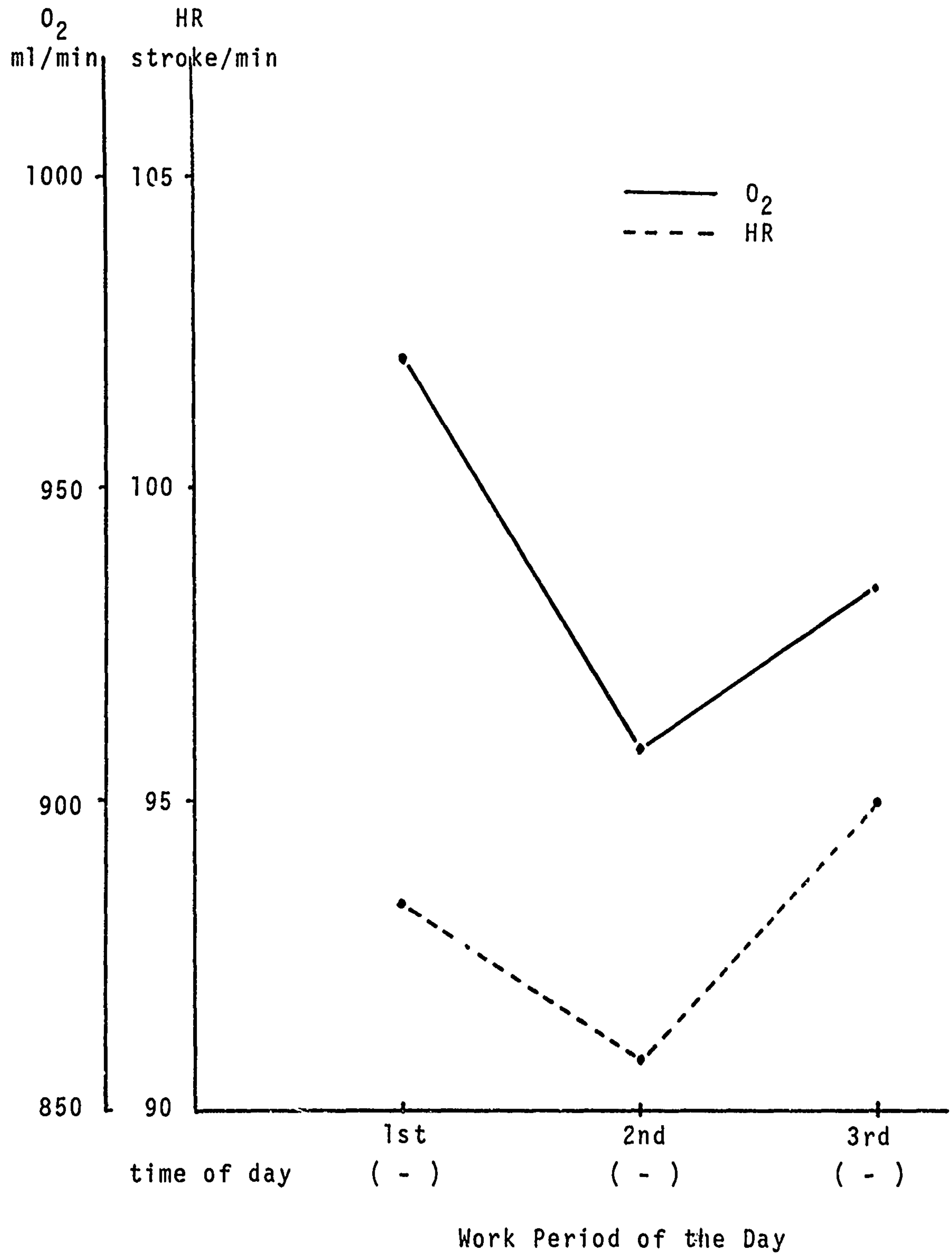


Figure 28. Overall Means

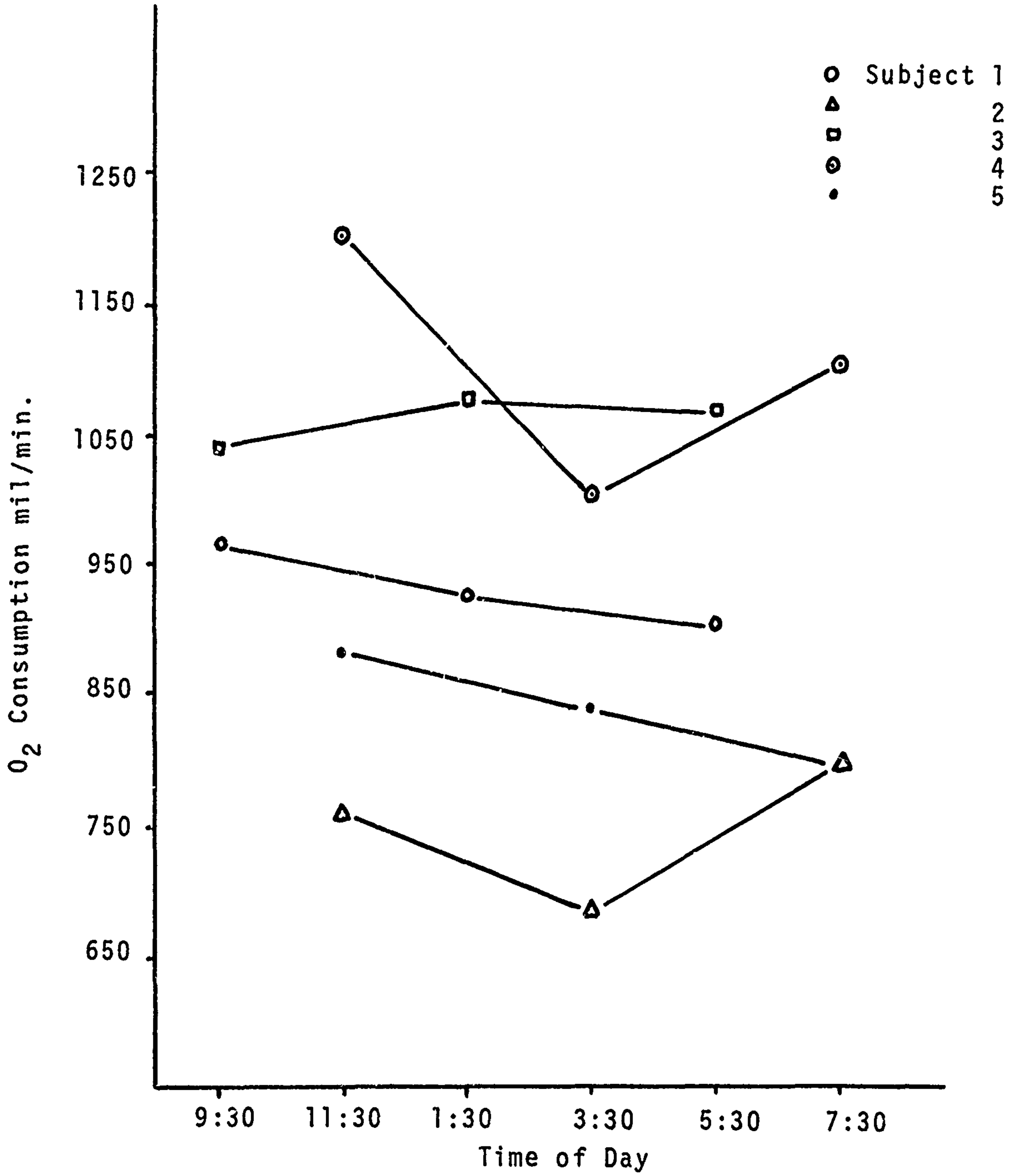


Figure 29. Subject Means

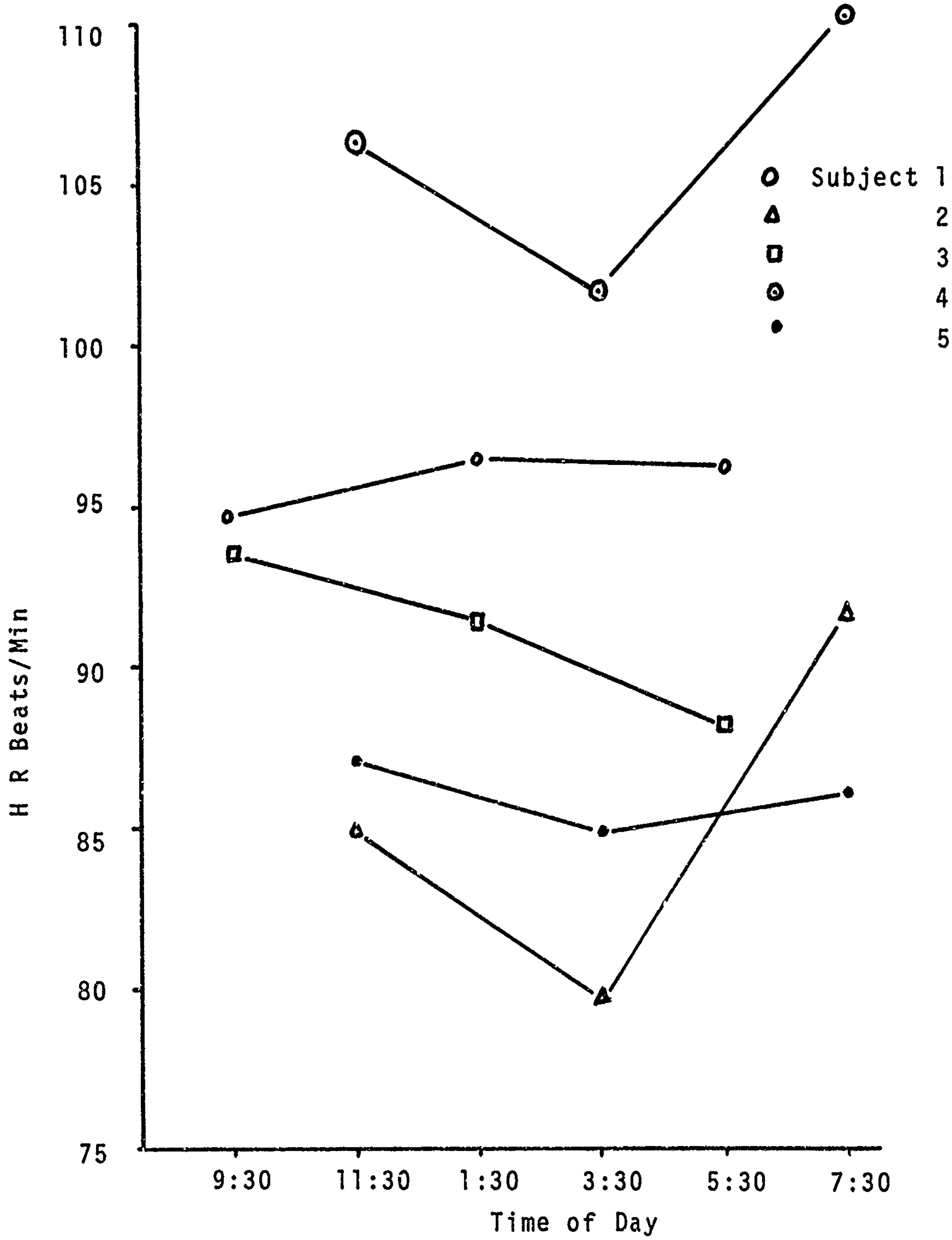


Figure 30. Subject Means

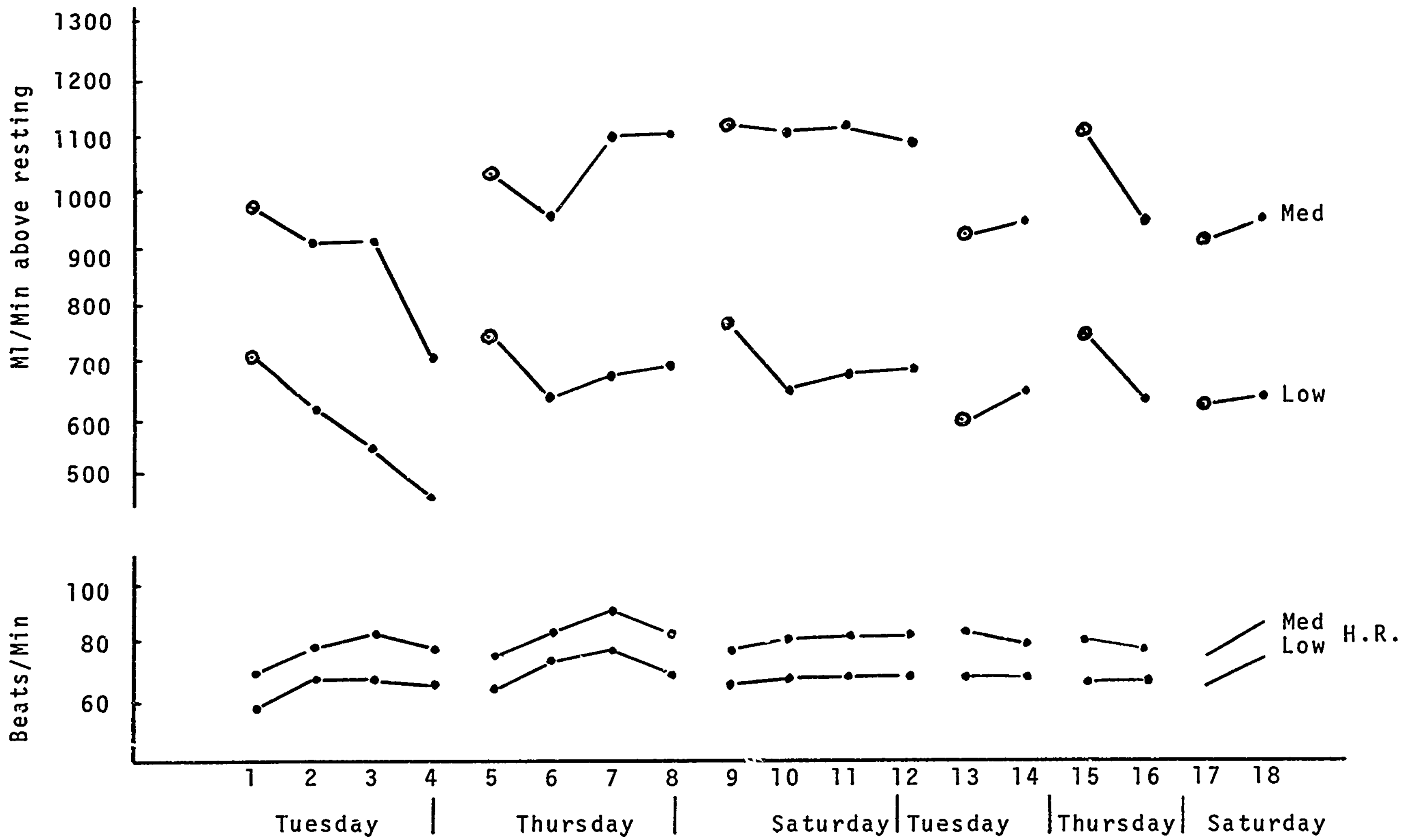


Figure 31. Heart Rate and Oxygen Consumption versus Day of the Week (Subject 1)

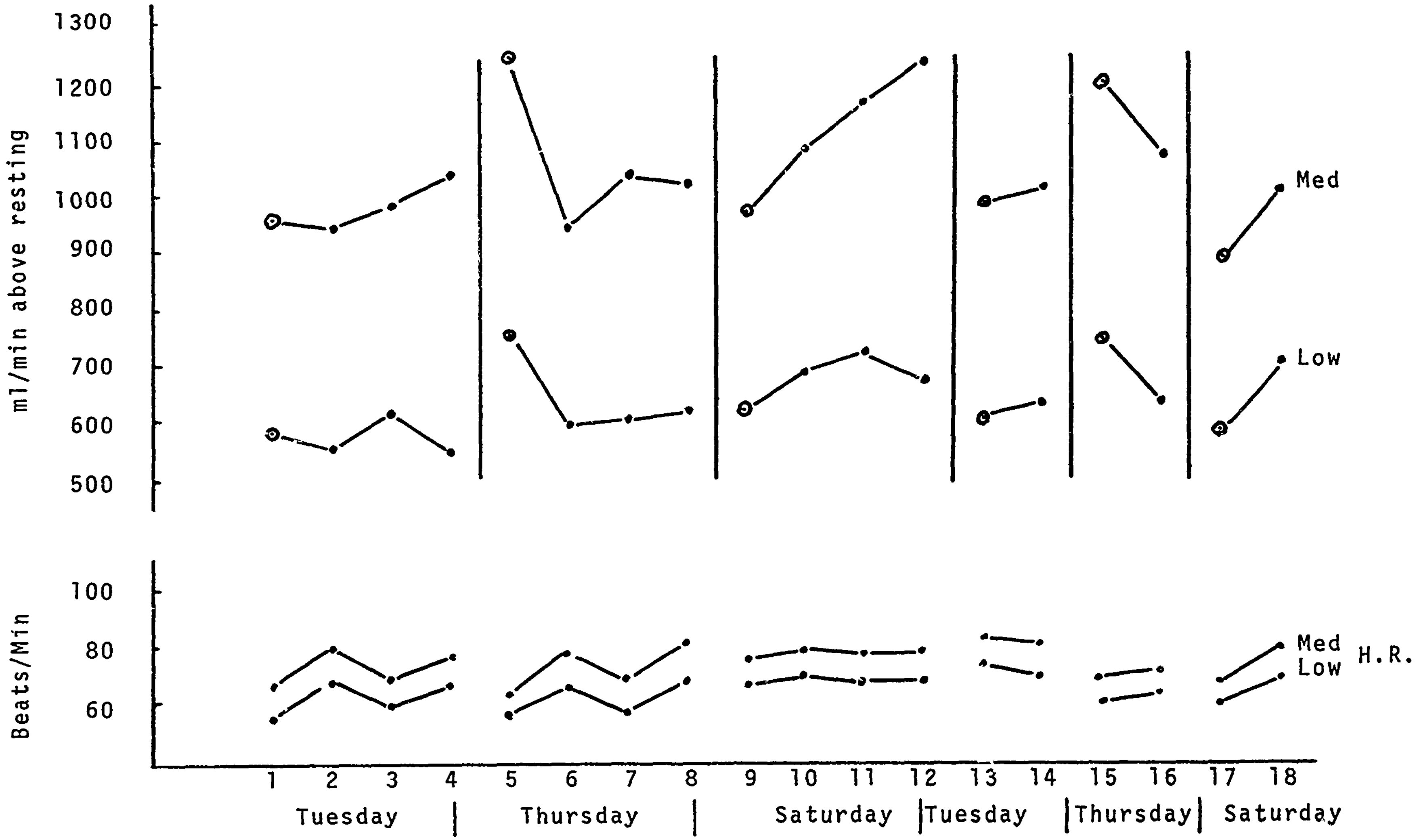


Figure 32. Heart Rate and Oxygen Consumption versus Day of the Week (Subject 2)

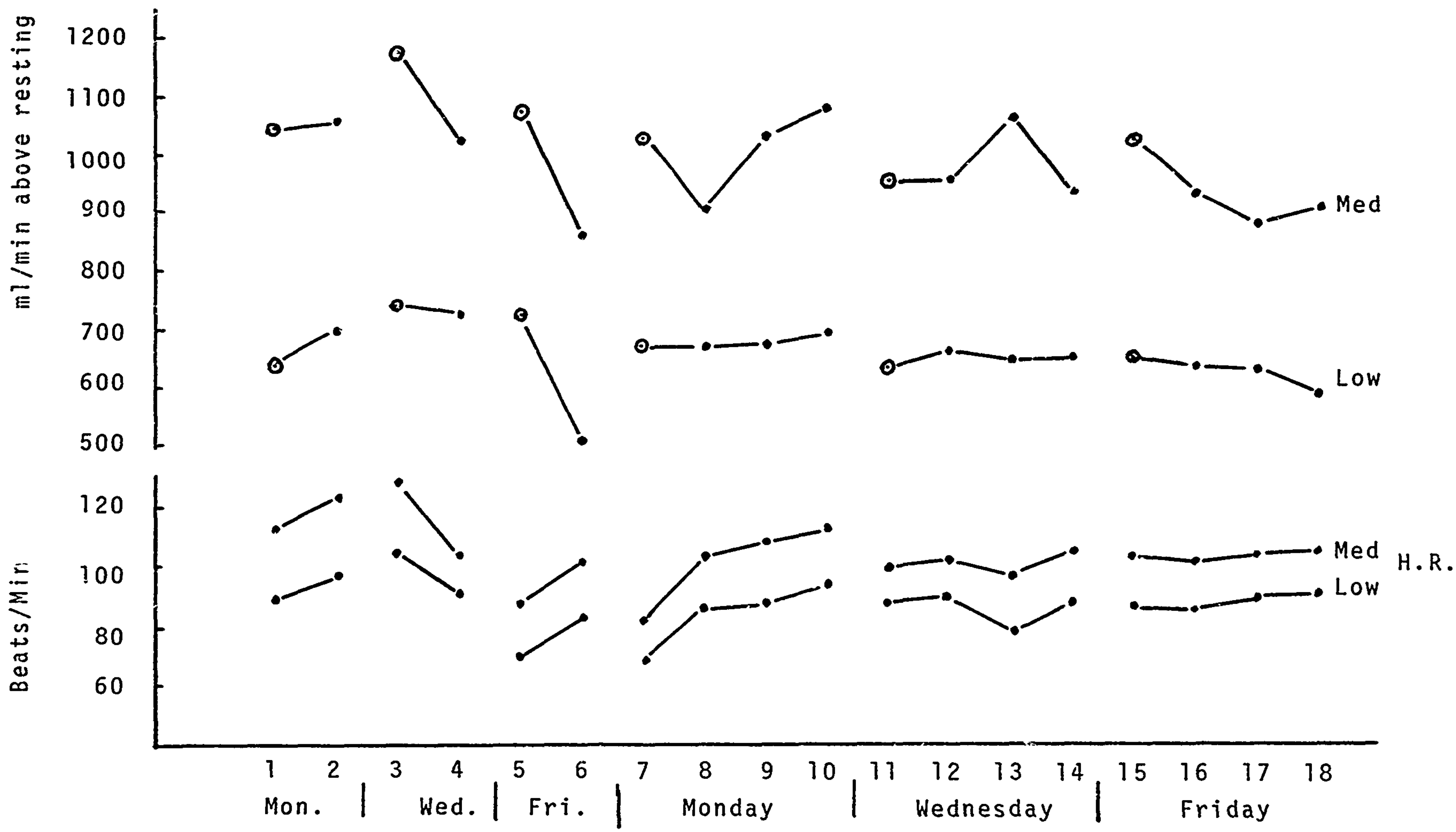


Figure 33. Heart Rate and Oxygen Consumption versus Day of the Week (Subject 3)

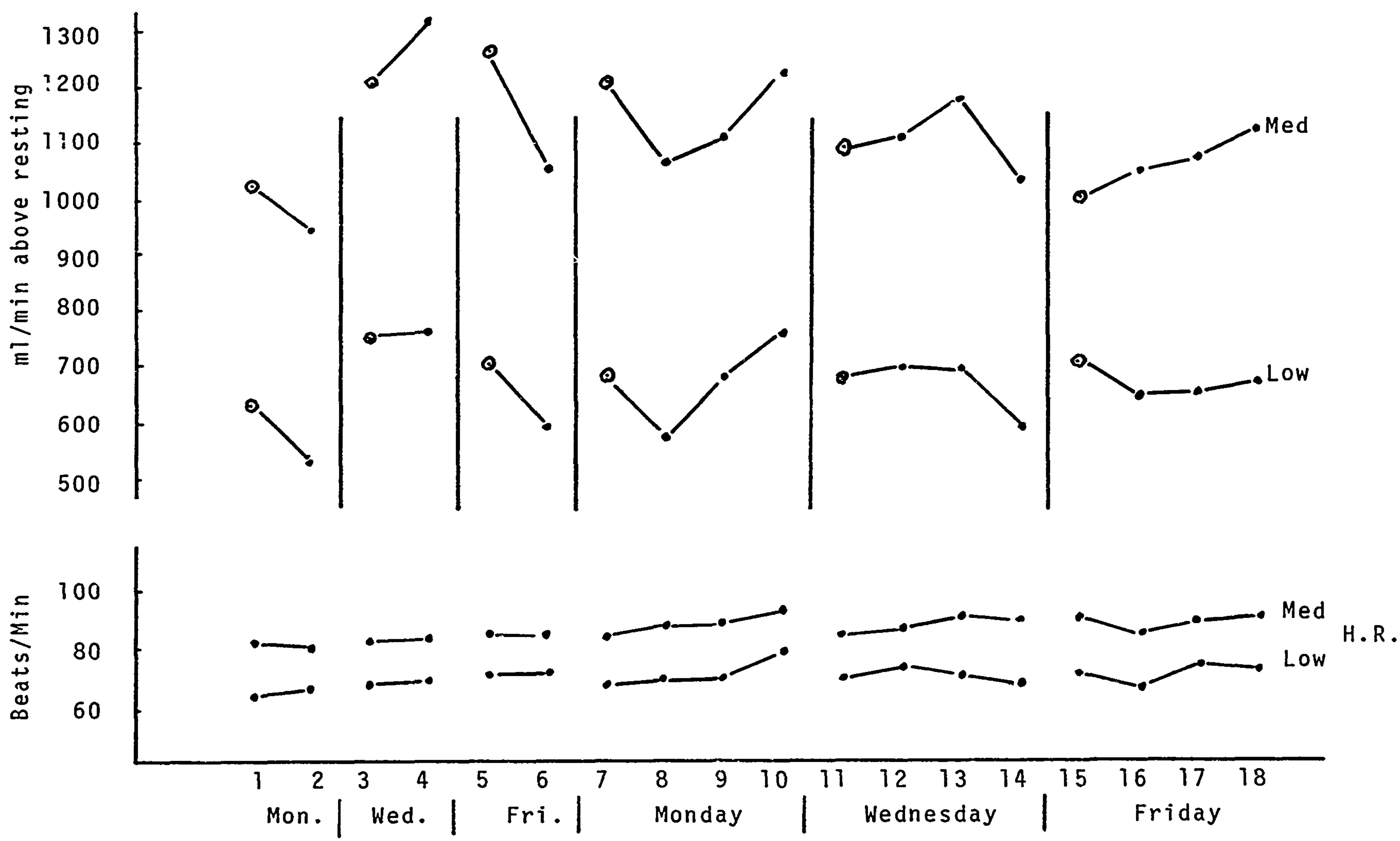


Figure 34. Heart Rate and Oxygen Consumption versus Day of the Week (Subject 4)

to afternoon. In addition to showing variation in the values obtained with regard to time of day, these graphs also show differences with regard to day of week.

Thus it can not be assumed that values for physical performance obtained at the same time each day are comparable and that any variation is due to an experimental treatment. This is also true for the tracking task as shown in Figure 35. Error scores for 5 minute intervals and total error showed an increase from Monday through Thursday and slight decrease on Friday with the exception of the first 5 minute period which showed an increase on Friday. The decrease on Friday cannot be simply attributed to an "end-spurt" since the subjects knew they would be coming in for runs on Saturday and Sunday. Since the week end runs were scheduled at different times of the day, they were not compared to the week day runs.

In addition to the error score increasing during the week, it also increased during the work period as shown in this figure. The rate of increase is fairly steady on Monday and Tuesday, then more fluctuation occurs during the next three days. This is probably influenced both by boredom and a learning effect. However, since most subjects had worked on the task for about 3 hours before Monday, any learning effect seems rather late in appearing.

It is hoped that periodic analysis of these data using a special program by Dr. Halberg will show some potential physiological measurements that can be related to performance levels. Such correlation could possibly be useful in evaluating the amount of physical loading for an individual, determining the effect of experimental treatments applied over a period of time, scheduling of optimum times for work, etc.

From the evaluations that have been made using analysis of variance, a daily or circadian rhythm appears present in $O_2$ consumption and HR during the alternating physical loading

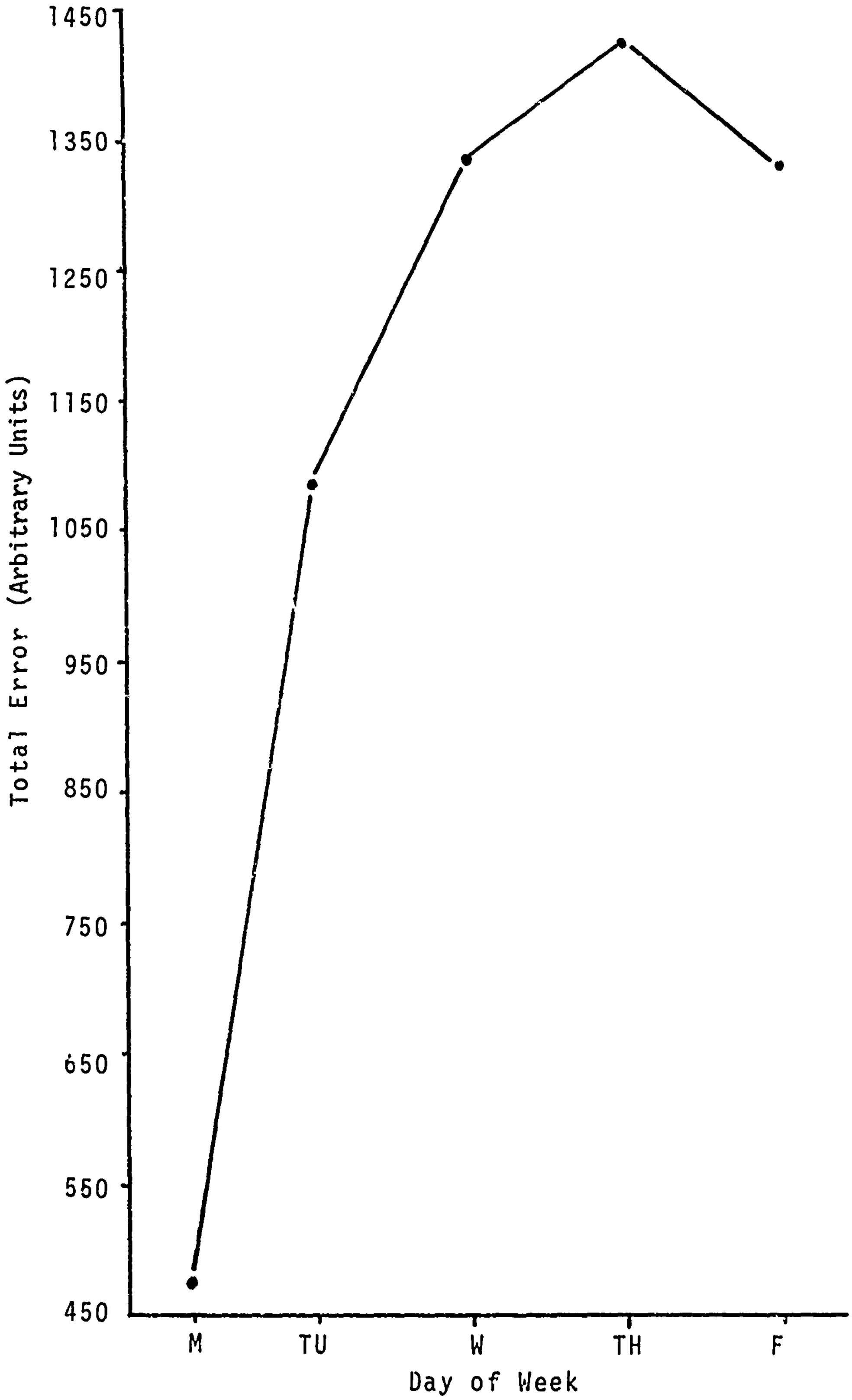


Figure 35. Effect of Day of the Week on Error Score

task and a weekly cycle present for the tracking task. The fluctuations present in the data for the 8 and 16 hour study appears to be influenced by both circadian and weekly rhythms.

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DISCUSSION SESSION

M. M. AYOUB

JAMES O'HANLON: Perhaps I've just missed this, but how did you measure the physiological cost?

ED BURKHARDT: Net physiological cost reflected the $O_2$ for work and recovery using rest as base line, per kilogram per body weight.

M.M. AYOUB: I don't think it was based or divided by body weight. The net physiological cost was in terms of liters/min. based on the work time.

JAMES O'HANLON: So I could conclude that the man's aerobic capacity is about 3 liters. This man's maximum capacities is about 3 liters.

M.M. AYOUB: Just about. We have had people rated between 3 1/2 and 4.2 liters.

JAMES O'HANLON: But these are average, young, well conditioned men?

M.M. AYOUB: Correct and each one was loaded depending on his own maximum capacity.

BEN B. MORGAN, JR.: What reflects sensitivity of the measure and I noticed on the individual being that you're showing, you don't show any change prior to the guy's termination. You think that if the man were sensitive enough you would see some change before he decided to terminate the experiment.

ED BURKHARDT: The termination primarily, well, I think the one greatest factor was blisters. We're also getting local fatigue. All of our subjects terminated although they could continue had they not had blisters.

JAMES O'HANLON: This data reminds me of other researchers who found that $O_2$ didn't change but the heart rate gradually increased throughout.

BEN B. MORGAN, JR.: I think there is some evidence here for a weekly kind of cycling. I'm not quite familiar with what it is, but in view of Adams, Alluisi and Martin, in 1961 had some data.

NANCY BETHEA: Some of the work that Halberg has done, on physiological cycles has shown this. He has done quite a bit of work along this line, of course, he is now working even on yearly cycles, and 7 year cycles and other shorter cycles. I would like alternately to look at some of the shorter cycles and also

in addition to the urinanalysis. We used this because it is convenient to obtain with minimum subject problems. Blood analysis would be nice but after having a glucose tolerance test run, I'm not going to ask anybody to have one of these taken 4 or 5 times a day. Unless we have a physician working with us and can put in a nurse and lab technician, we just can't do this. But the next thing I would like to look at is saliva, and see if possibly we could pick up some of these things in the saliva even easier.

# THE CONFERENCE SUMMARY

Carl James Lange
George Washington University, Washington, D.C.

First of all, I would like to say that I think it was most appropriate to have the panel of Deans at a Conference of this type. The University's experience in managing a large scale, interdisciplinary THEMIS program is most interesting and would be of value to other research groups initiating such ambitious projects. Interdisciplinary, problem centered research efforts are "hot" currently and the experiences here should be published. I would like to suggest that you report them in, for example, JOURNAL OF HIGHER EDUCATION, or some other appropriate journal on Higher Education.

I will not attempt to summarize the many excellent empirical studies which have been reported during the conference. They represent a substantial contribution to knowledge about human performance under sustained work conditions. Rather than attempt a summary of these results reported, I would like to offer some general observations concerning research strategy.

Now, it seems to me that we need a more precise definition of continuous operations. Perhaps we need the kind of military analysis that will allow the Army to establish a possible "stopper variable."

By that, I mean, for example, performance for a period of time that would represent the minimum duration necessary for continuous operations to be successful. Then, the necessary research could be done to determine if this minimum performance can be met. In short, the critical performance requirements need to be specified and research findings developed as to whether or not such requirements can be met.

What I'm more specifically thinking of here is the minimum duration of work/rest cycles that would be required before

relief in the combat operation situation. Can this be identified in order for the continuous operations concept to be militarily feasible? Then, related to that within the work cycle, what is the work performance requirement for combat units in order to make the concept feasible? Can we say now whether this minimum work requirement could be met without crippling and disastrous effects on the troops involved?

I'm thinking specifically here of what seems to me a contradiction in the assumptions about this particular matter. That is, on the part of the Physiologist in assuming that prolonged physical activity was required, as I understood it, that goes beyond the normal limits of the troops. In contrast to that, the assumption seemed to be made in the BESRL study that there was indeed time in combat operation for periods of work and rest such that troops could endure satisfactorily.

If continuous operations would appear feasible after such an analysis, then it would appear to me that it would be timely to undertake a fairly comprehensive integration of available research results from the various sources, both laboratory and field studies. This would take the form of a continuous operations handbook to make explicit the adequacy of research findings for military operations. I think that, in the process of developing such a handbook, you might go a long way towards forcing the surfacing of a precise definition of what the more specific military requirements are. You may very well raise some questions about what the military requirements are in terms of work/rest cycles, recovery rate, etc. I don't know what the status of the military literature is in terms of such handbooks for conventional activities, but it occurred to me that it wouldn't make a great deal of difference whether continuous operations were a feasible concept or not. Putting together this information and bringing out the "so what" explicitly for military operations, would be valuable for conventional warfare as well.

Now in terms of specific suggestions for future experimental work, both in the laboratory and in field settings, it struck me that the discussion of the various work in laboratory settings had a lack of emphasis on team variables or group motivation variables that could well interact with the performance decrement results. I'm thinking of the work that Clay George did when he was at Fort Benning on the induction of a team task orientation within groups. This sort of thing could well have a positive influence on either the reduction of decrement or elimination of some of it. This general kind of variable would be well to include in multi-variate experimental studies in the future.

In the experimental field study situation, it seemed to me that one could justifiably call for somewhat more sophisticated designs in some of the field studies, especially in view of the expense in carrying them out. Again specifically, I am thinking here of including careful consideration of leadership variables and group motivation variables. These, in fact in past research, have been shown to have influence on group performance and certainly I think we would be wise to incorporate them in any future field studies.

I think both of these kinds of considerations would suggest a requirement for more effort at theoretical conceptualization of problems in terms of mixes of variables and their probable interactions. This kind of conceptualization could be used to produce designs for what would be critical experiments in terms of a theoretical analysis. I recognize so well pressures that are probably put on people who are doing field research. They may well not be in a position to carry out such analyses. It is, therefore, conceivable that a natural split of this kind of work would be to rely on contract research with university researchers to undertake the more intensive theoretical conceptualization that requires digging into the literature, etc., and coupling that with those working on the field studies.

Some of us were kicking around the notion that the characteristics of troops that are available for experimental work change

every 5 to 7 years or so, if not more frequently. Back when I was involved with this kind of thing, we had troops that were aged up to perhaps 30 that we used in our experimental work. Now, in these more recent experiments of yours, troops range in age from 18 to 22. I think these age differences can make a substantial difference in these kinds of results. So some explicit statement of assumptions about future Army populations, for example, would have implications for what type of subjects are to be used for the experimental work. Or do you do experimental work across a wide variety of age ranges?

Similarly related to this would be the question of experience in either training or combat operations and also related to that would be assumptions concerning available time for training. Are you going to be pushing troops through very condensed training or is the assumption for more leisurely training programs? Another kind of consideration is the general type of war. Is it going to be a limited type of Viet Nam conflict or some variety of all-out war. I think this would have important implications for overriding motivational factors about what level motivated troops you are working with. To reemphasize a point formerly made: Some type of operations or systems analysis is needed to identify the points of the system of greatest stress relative to the question of feasibility of continuous operations concepts and then to specify the necessary tests to determine if troops can endure to meet the minimum performance requirement.

I also suggest as a kind of an obvious thing, if this program of continuous operations continues, that it would be extremely desirable to have this sort of conference among those participating on a more systematic basis and perhaps with a schedule where you could treat more intensively a particular aspect of it. The next conference could go into this more intensive discussion of what are the military requirements, classifications, etc. I think that this notion of bringing everybody together is a very laudable one and could certainly prove to have an effect if it were done on a more regular systematic basis.

As a final comment, Clay George dropped a comment fairly early in the conference and I happen to feel very strongly about it and I don't what it to be overlooked. That is I think that we have to be very careful in our reductionistic approach to doing laboratory experiments not to overlook the impact of what are uniquely human characteristics. The outstanding uniquely human characteristics to me is the extremely strong motivating force to support one's comrades, especially when under real stress and this factor, this motivational consideration is one that I think needs to be kept in mind always when extrapolating from either laboratory or field situations because you never really duplicate operational conditions. As a consequence, it can lead to an expectation of performance or achievement decrement that would not, in fact, occur in a real situation. I don't have any particular wisdom on how to incorporate this, but I think it is an extremely important point to keep in mind throughout the consideration of the problem.

## DISCUSSION SESSION

## CARL LANGE

WILLIAM HARRIS: I would like to underscore a couple of comments you made about subject variables. One is age. The effect of age has not been very well studied. Most of the subjects in sleep deprivation studies, etc., are young healthy adults. But military commanders tend to be older, naturally. And the modern volunteer Army, if it really comes into being, will likely result in an increase in the average age of men in service. So I think we need to begin systematically investigating the interaction of age and fatigue in performance on various types of tasks.

Another thing that we have mentioned is the effect of group behavior and motivated individual behavior on continuous operations performance. These things are obviously important, but they cannot readily be measured in empirical studies. Men under fire or in operational settings have to have high morale and some emotional support from the team or unit.

CLAY GEORGE: I would like to ask everyone to keep the soldier's load in mind. R&D people are continuously giving him new gadgets to use and carry, and the soldier will, in addition, tend to load up on ammunition. This brings us back to a stress conference we had some years ago where we discussed the soldier's control of his own fate. If he feels that he has some control over his fate, he can work better in a tiring or stressful situation than he can if he doesn't. Logistics, artillery and air support notwithstanding, the way the infantryman controls his fate is by means of his individual weapon (rifle) and the ammunition he carries. So he loads up on ammunition, takes good care of his rifle, and throws away other equipment as he gets tired of carrying it. Thus, most of the time he is going to be more heavily laden than the tables indicate he should be, because of the extra ammunition and water he will carry. The soldier will likely throw his food away before he will lighten his ammunition load. So we should try to obtain some realistic information about combat soldiers' loads, so the physical labor that is really involved in continuous operations can be taken into account.

REX DAVIS: Along this same line, one should consider some of the morale factors of the medical care that is immediately available. During continuous operations, you may not be able to send in the amount of medical support that you would want to. This will have a distinct effect on the morale of the troops.

CLAY GEORGE: Absolutely, I think generally we are saying that we ought to talk to the infantryman more often, and we ought to try to see the situation from his point of view. His behavior is marked by a number of things not really under the planners' control. If we can walk in the infantryman's boots for a little while I think it would help us understand the amount of physical loading he experiences and the amount of emotional strain.

JAMES O'HANLEN: I would like to add something at this point concerning the matter of fate control. You said that it was better if the soldier, in some cases, had better control of his fate. Yet it appears from one war in particular--Viet Nam--that troops are sometimes so completely isolated (in fact, surrounded by hostile forces) that if the men weren't totally aware of the situation (such as the enlisted members of Special Forces units) they were under less stress physiologically than their commanders. Surprisingly, the officers in charge and their radiomen, who were completely aware of the situation and aware of the dangers involved, became more fatigued. And their ability to stretch and share the emotional burden was more limited than was true in the case of the typical trooper.

DAVID HODGE: I would like to re-iterate a point I have made before. It seems to me that there has been a lot of research by various groups without a common rationale, and without a theoretical model that can be utilized to develop hypotheses to test. I will concede that in the past there may not have been sufficient empirical information about long-term performance, work/rest cycles, sleep deprivation, etc., to support development of these models. However, it seems to me that at some point we have to begin developing some kind of theoretical position. Otherwise, we simply drift into doing whatever comes to mind--conducting whatever experiment occurs to us, for its own sake. The thing that was clearly lacking at this conference was the presentation of a group of systematic hypotheses to be kept in mind during experimentation. We need to arrange our information more systematically, so we can try to predict the most reasonable experiment that should be done next, and how it relates to military requirements for information in this area.

## PROGRAM SUMMARY

28 September 1971

0900 Welcoming Address: Grover E. Murray, President, Texas Tech University

0905 STATEMENTS OF THE CONTINUOUS OPERATIONS PROBLEM

Remarks on Research Requirements for Continuous Operations:

Jacob L. Barber, Behavioral Sciences Division, Office of the Chief of Research and Development, Department of the Army, Washington, D. C.

Trends in Current Research: Louise B. Speck, Concepts and Force Design Group, USA Combat Developments Command, Washington, D. C.

1045 UNIVERSITY INTERDISCIPLINARY RESEARCH PANEL

J. Knox Jones, Dean, Graduate School

Lawrence L. Graves, Dean, College of Arts and Sciences

John R. Bradford, Dean, College of Engineering

1300 SPECIFIC HUMAN FACTORS PROBLEM AREAS

Environmental Quality Requirements for Continuous Operations:

David C. Hodge, Human Engineering Laboratory, Aberdeen Proving Ground, Md.

Field Research With Small Military Units: James H. Banks, USA Behavior and Systems Research Laboratory, Fort Ord, California

Work-Rest Schedules Under Proplonged Vibration With Implications to Military Operations: R. A. Dudek, M. M. Ayoub, M. A. El-Nawawi, and T. M. Khalil, Texas Tech University

Self Determined Work/Rest Cycles in the Heat: J. D. Ramsey, C. G. Halcomb, and A. K. Mortagy, Texas Tech University

29 September 1971

0830 Applicability of Research on Sustained Performance, Endurance, and Work-Rest Scheduling to the Development of Concepts and Doctrine of Continuous Operations: Ben B. Morgan, Jr., and Earl A. Alluisi, Performance Research Laboratory, University of Louisville, Louisville, Kentucky

Some Observations from a Literature Review to Anticipate Biological Problems that Might Arise in Sustained and Continuous Operations: James F. O'Hanlon, Human Factors Research, inc., Goleta, California

Physiological Response to Prolonged Muscular Activity: M. M. Ayoub, Gene Coleman, and Nancy Bethea, Texas Tech University

1300 Conference Summary: Carl J. Lange, George Washington University, Washington, D. C.

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